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Hardesty

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(54) **SELECT FIRE SWITCH CONTROL SYSTEM AND METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 125 days.

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Related U.S. Application Data

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(51) **Int. Cl.**

E21B 43/11 (2006.01)
E21B 47/06 (2012.01)
F42D 1/05 (2006.01)
F42D 3/02 (2006.01)
E21B 43/1185 (2006.01)
F42B 3/02 (2006.01)

(52) **U.S. Cl.**

CPC **E21B 43/11857** (2013.01); **E21B 43/1185** (2013.01); **E21B 47/06** (2013.01); **E21B 47/065** (2013.01); **F42D 1/05** (2013.01); **F42B 3/02** (2013.01)

(58) **Field of Classification Search**

CPC E21B 43/1185; E21B 43/11852; E21B 47/06; E21B 47/065; H01H 1/58; H01H 11/00; H01H 11/04; H01H 11/06; H01R 43/18; H01R 43/20; H01R 43/28; Y01T 29/49105; Y01T 29/491047; Y01T 29/49169; Y01T 29/49174; F42D 1/04; F42D 1/045; F42B 3/00

See application file for complete search history.

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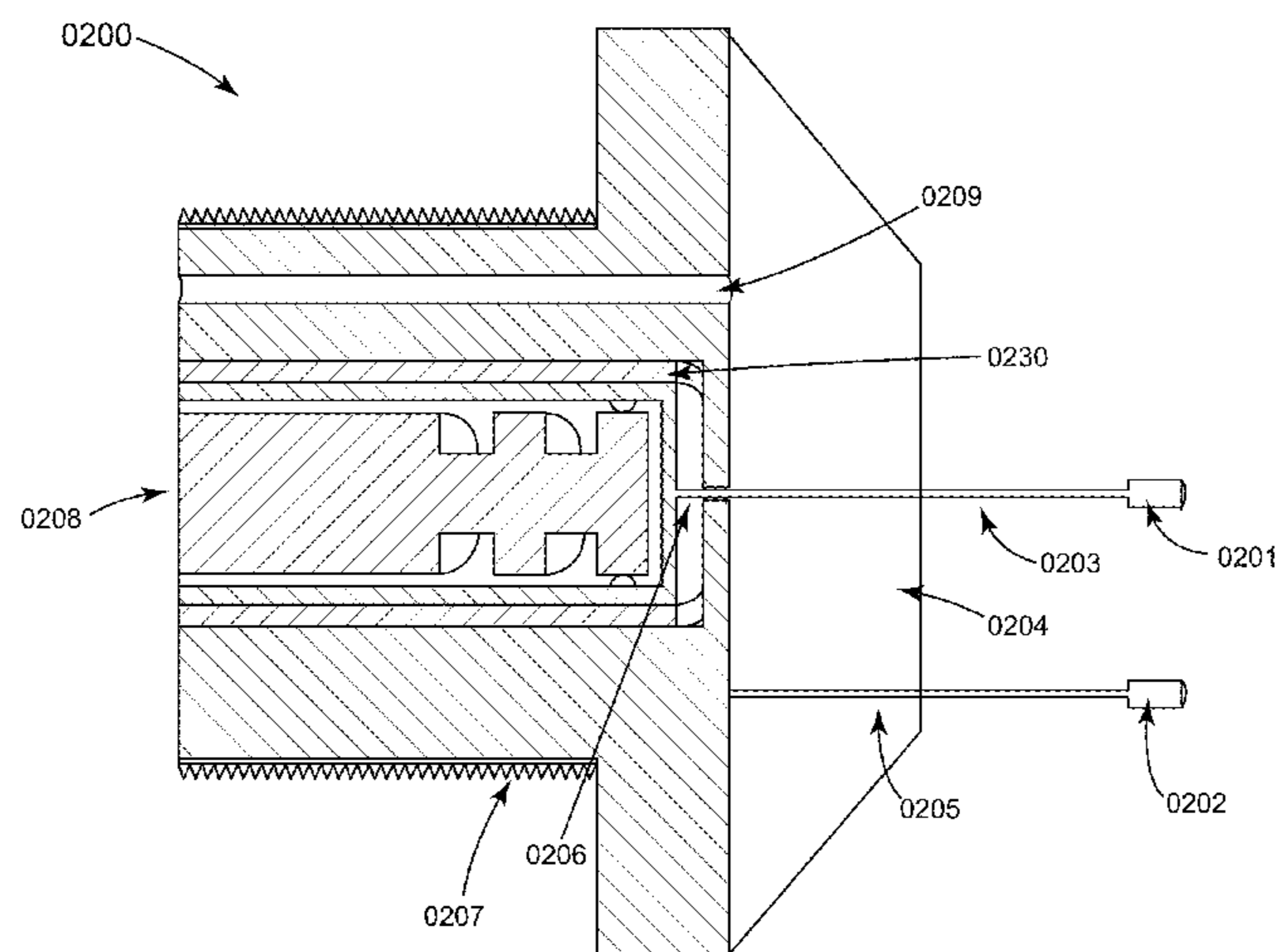
Primary Examiner — Jennifer H Gay

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(57) **ABSTRACT**

A select fire system and method for controlling operations in a gun string assembly includes perforating guns and switch subs mechanically connected in the gun string assembly. Each of the switch subs includes a switching element, input links and output links. The switch subs and perforating guns communicate with each other through the input and output links. The switching elements keep track of the state of the sub and switches states based on trigger conditions such as environment conditions, perforating gun conditions, or input conditions from surface.

12 Claims, 49 Drawing Sheets



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FIG. 1b

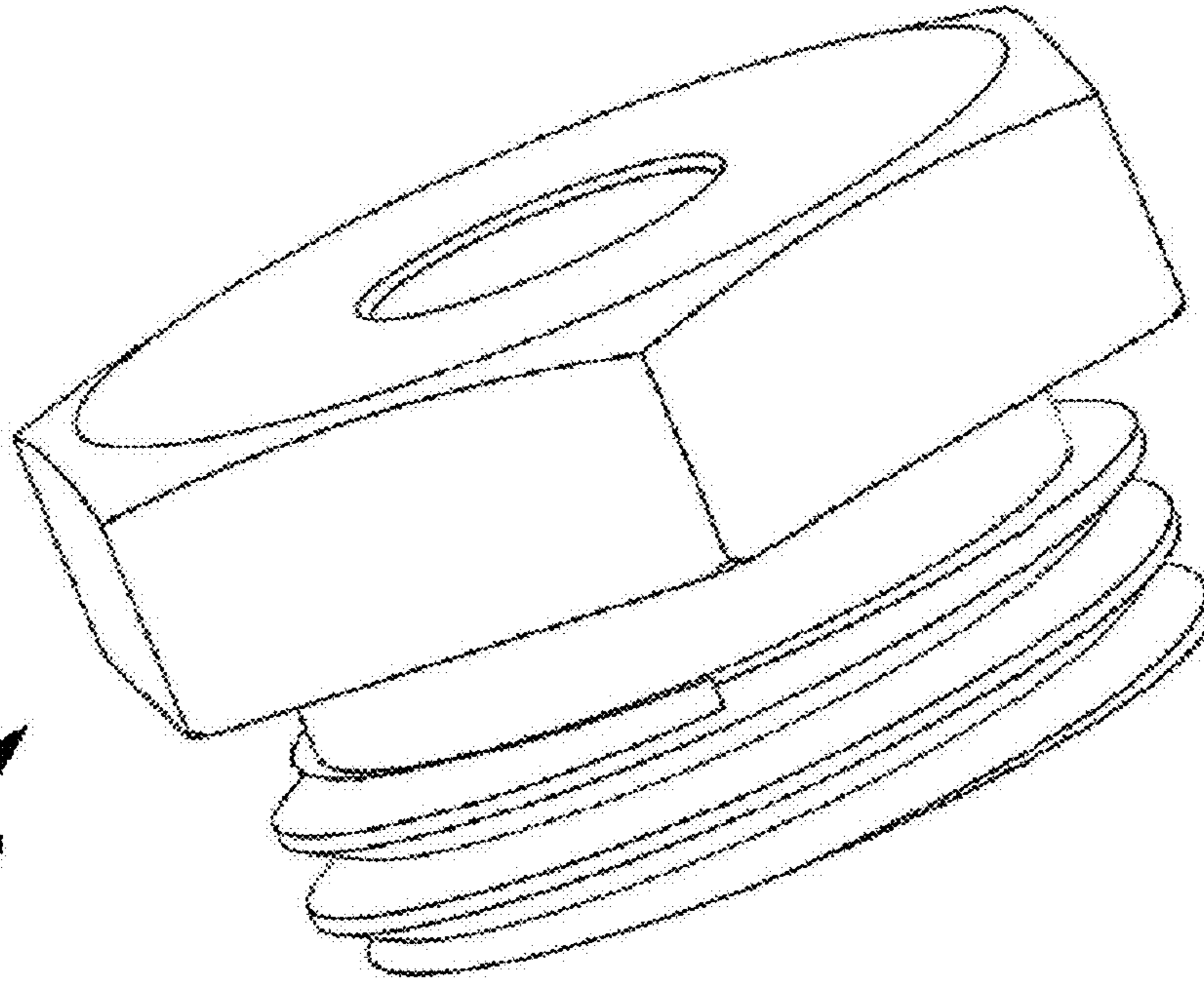
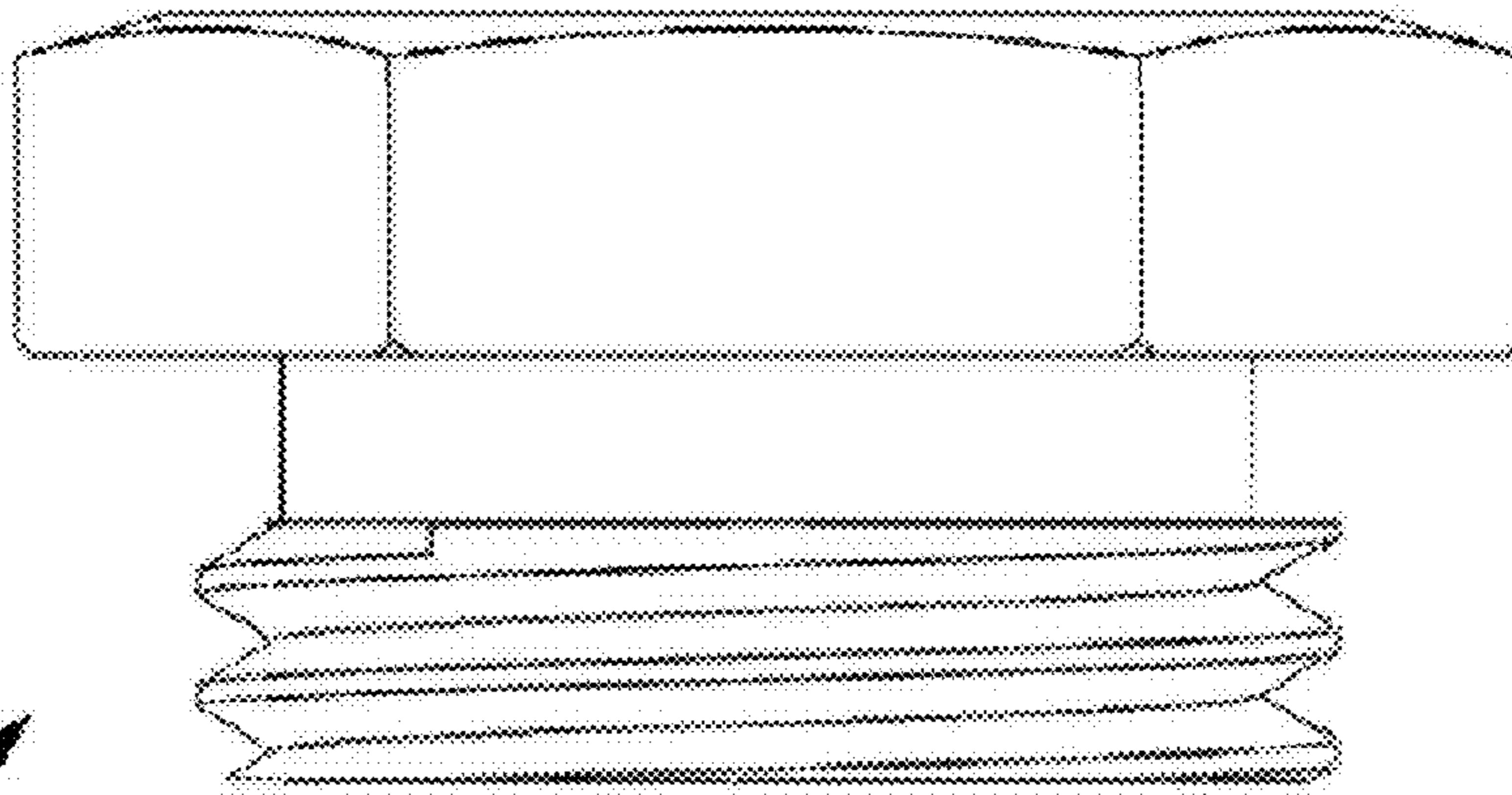


FIG. 1a



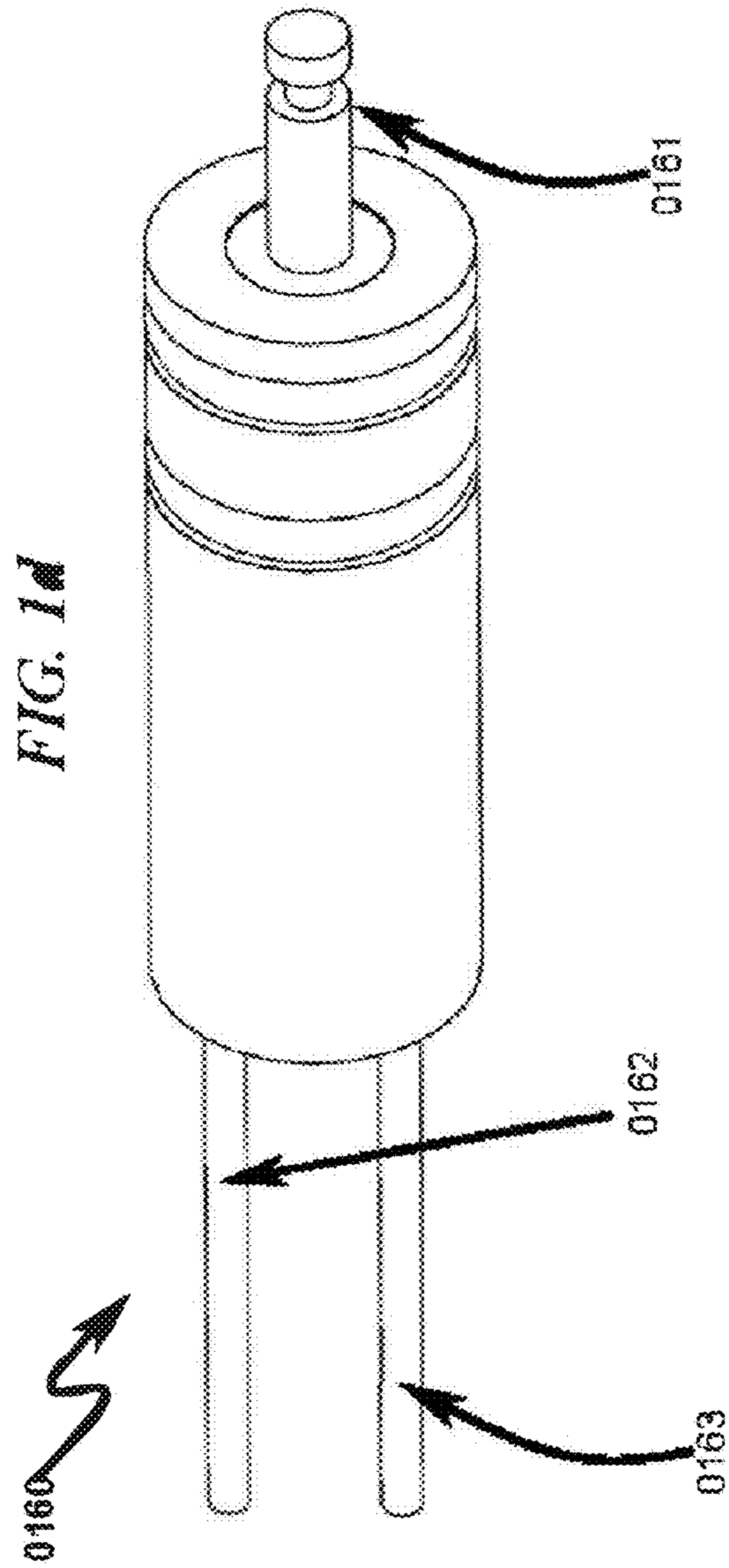
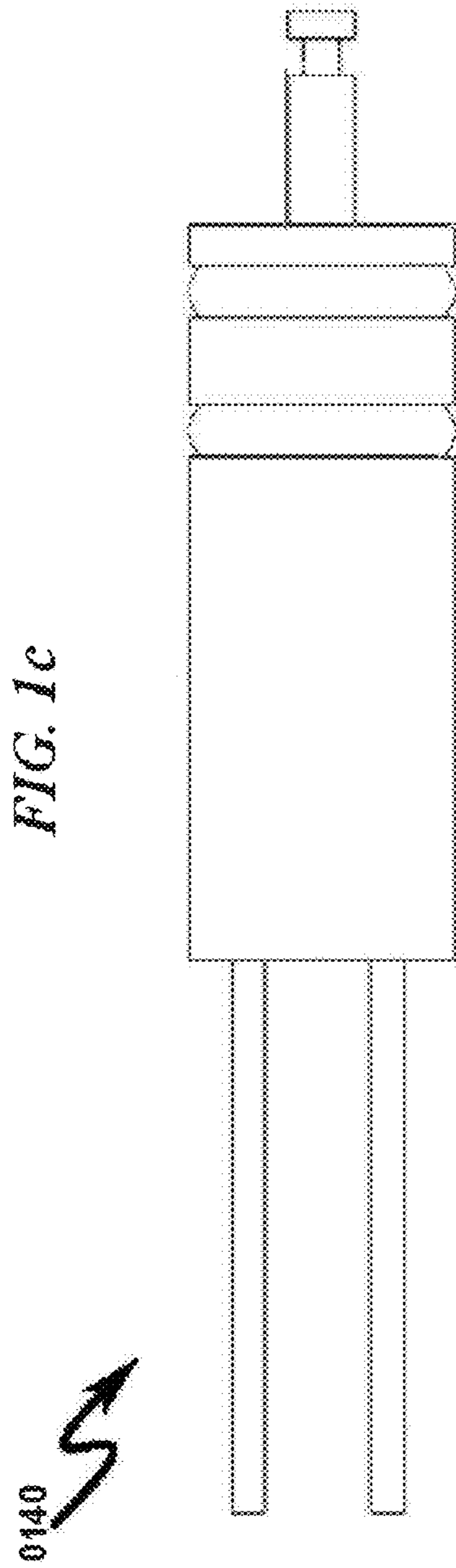


FIG. 2a

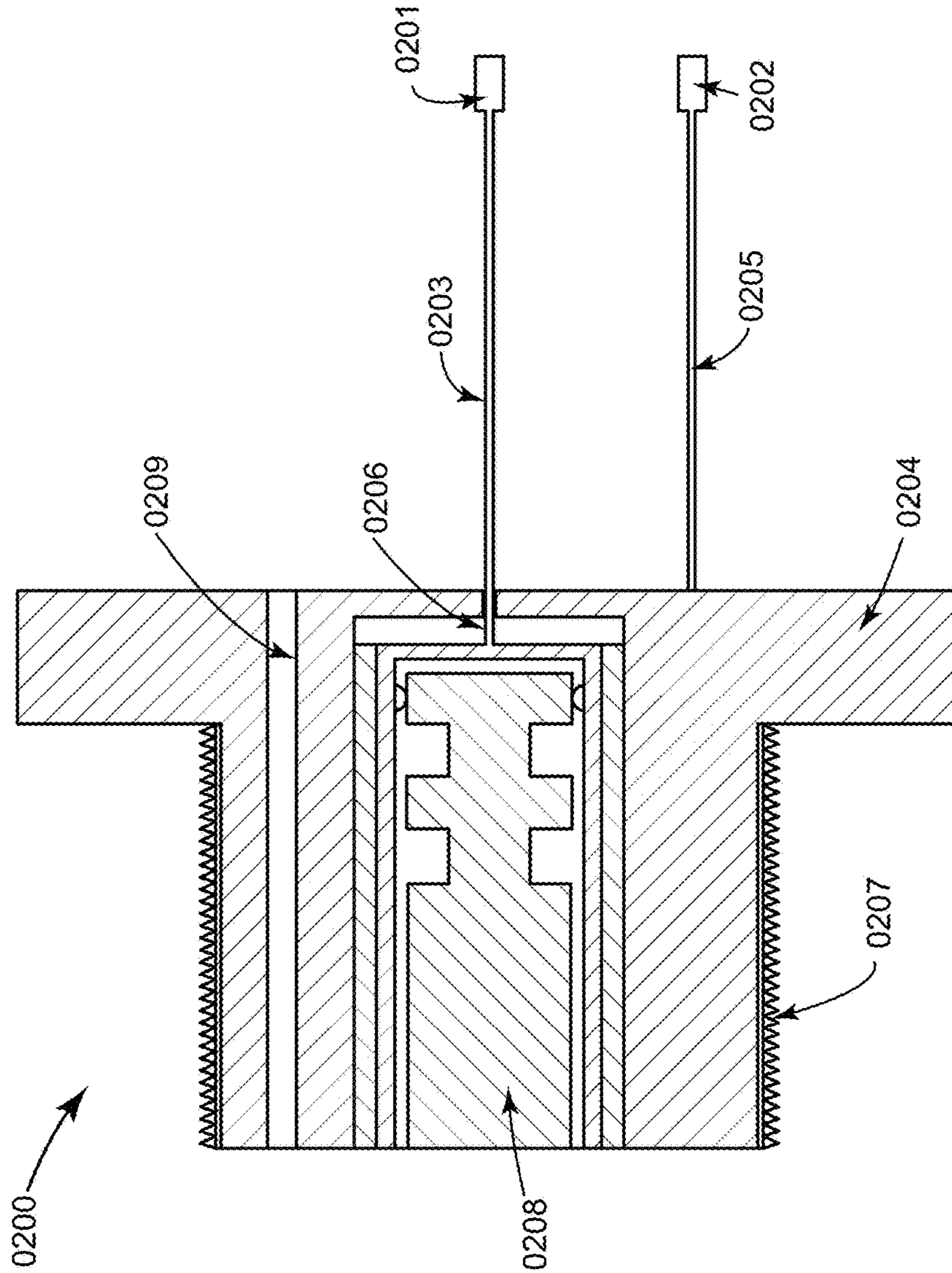
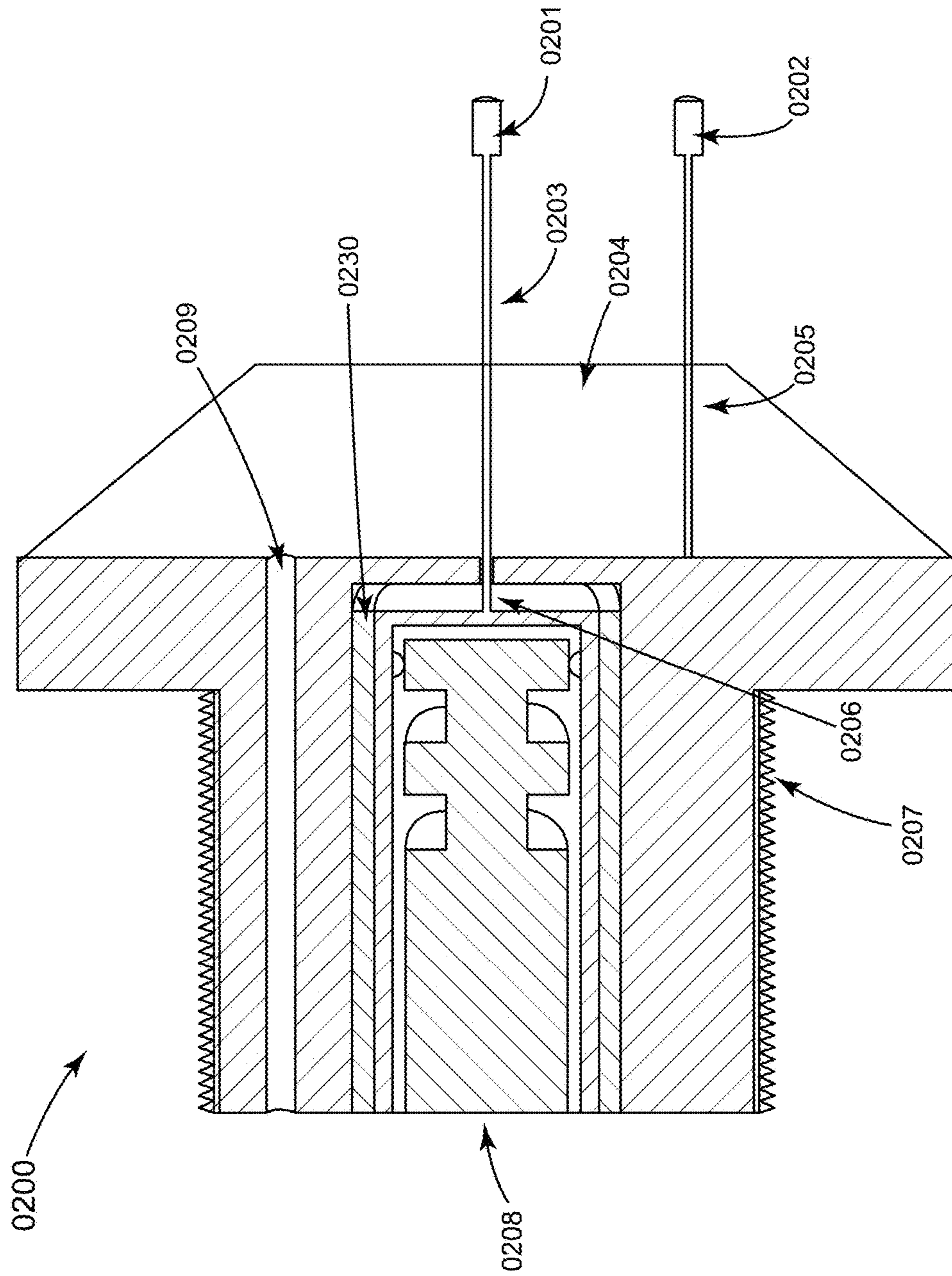


FIG. 2b



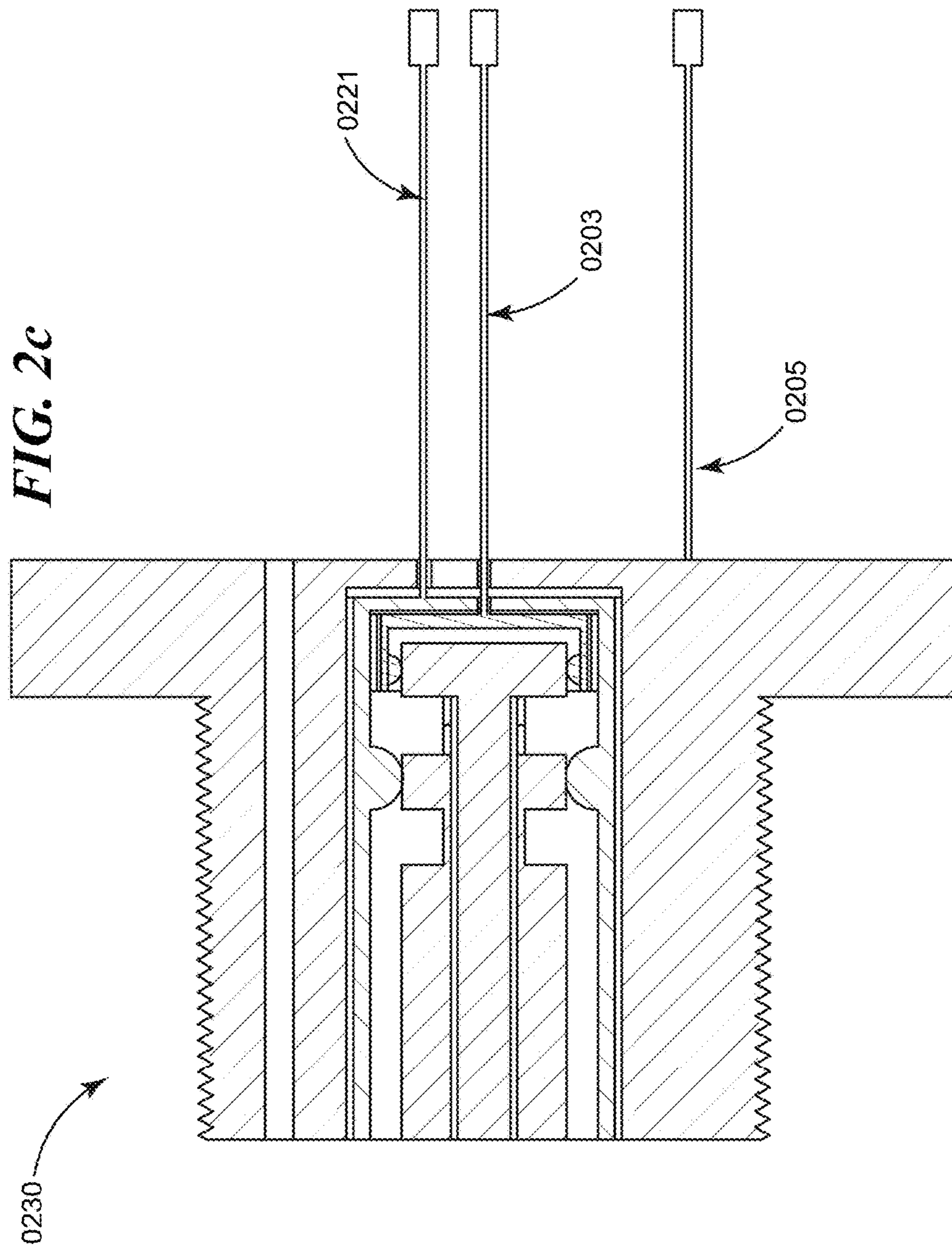


FIG. 2c

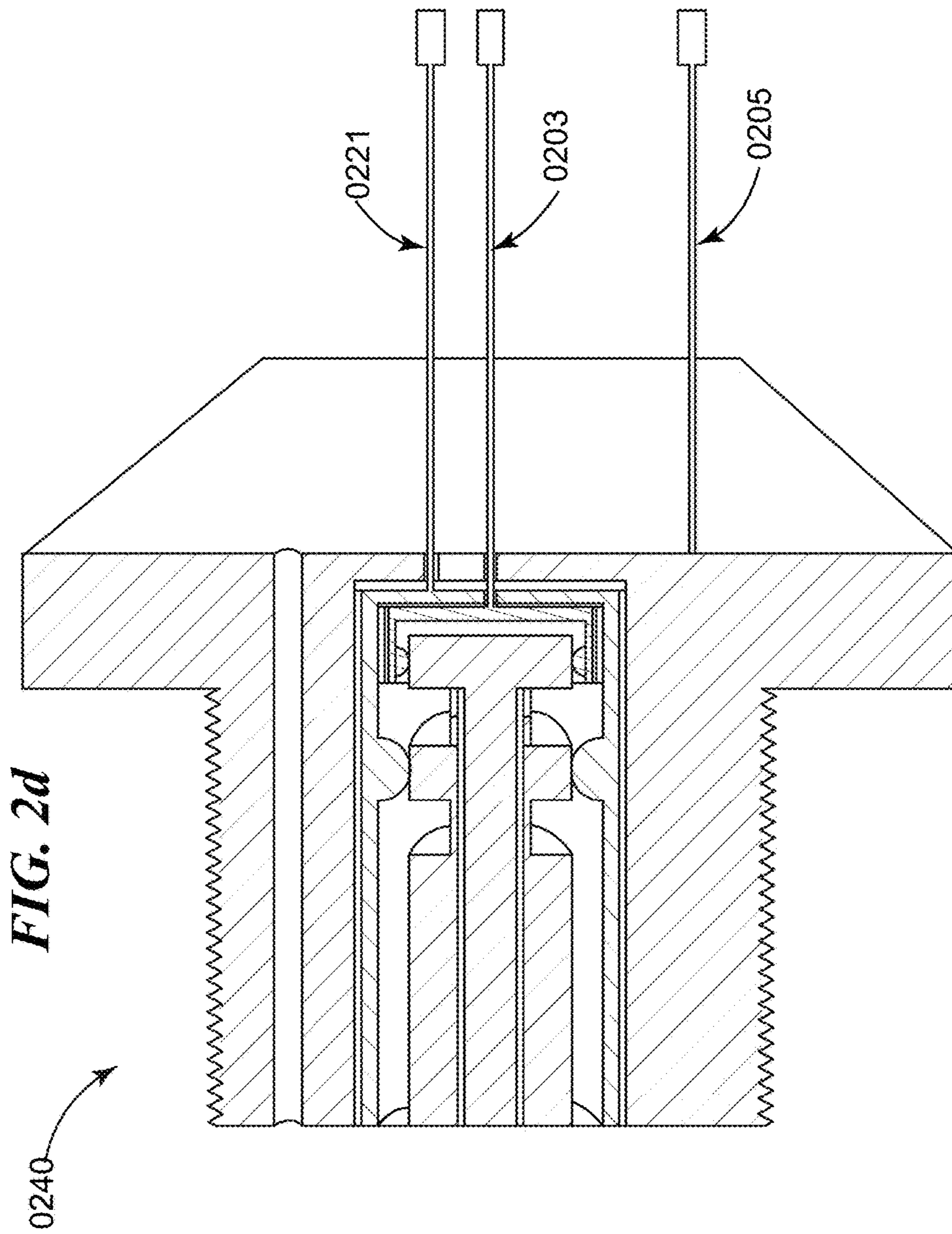


FIG. 2e

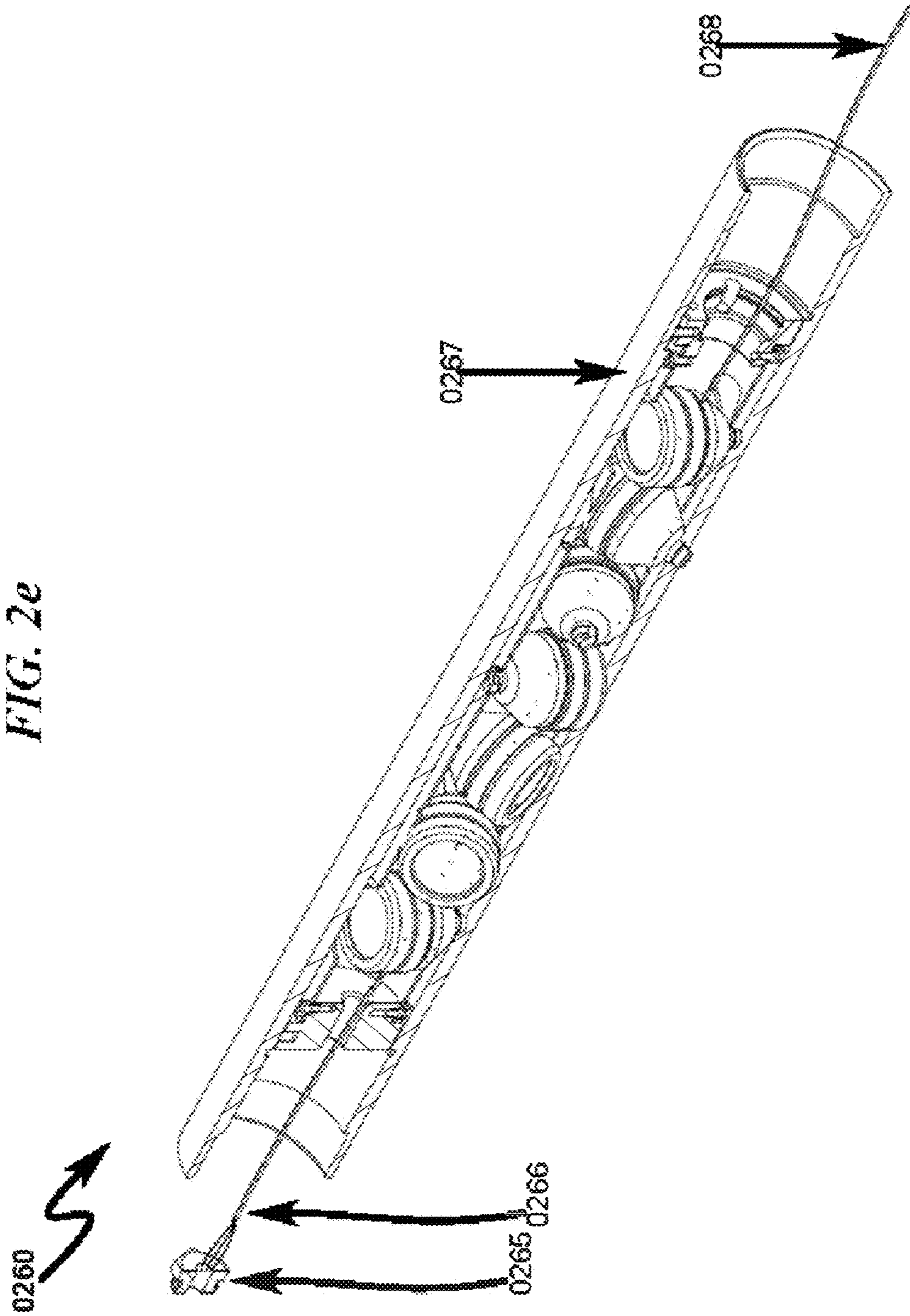


FIG. 3a

0300

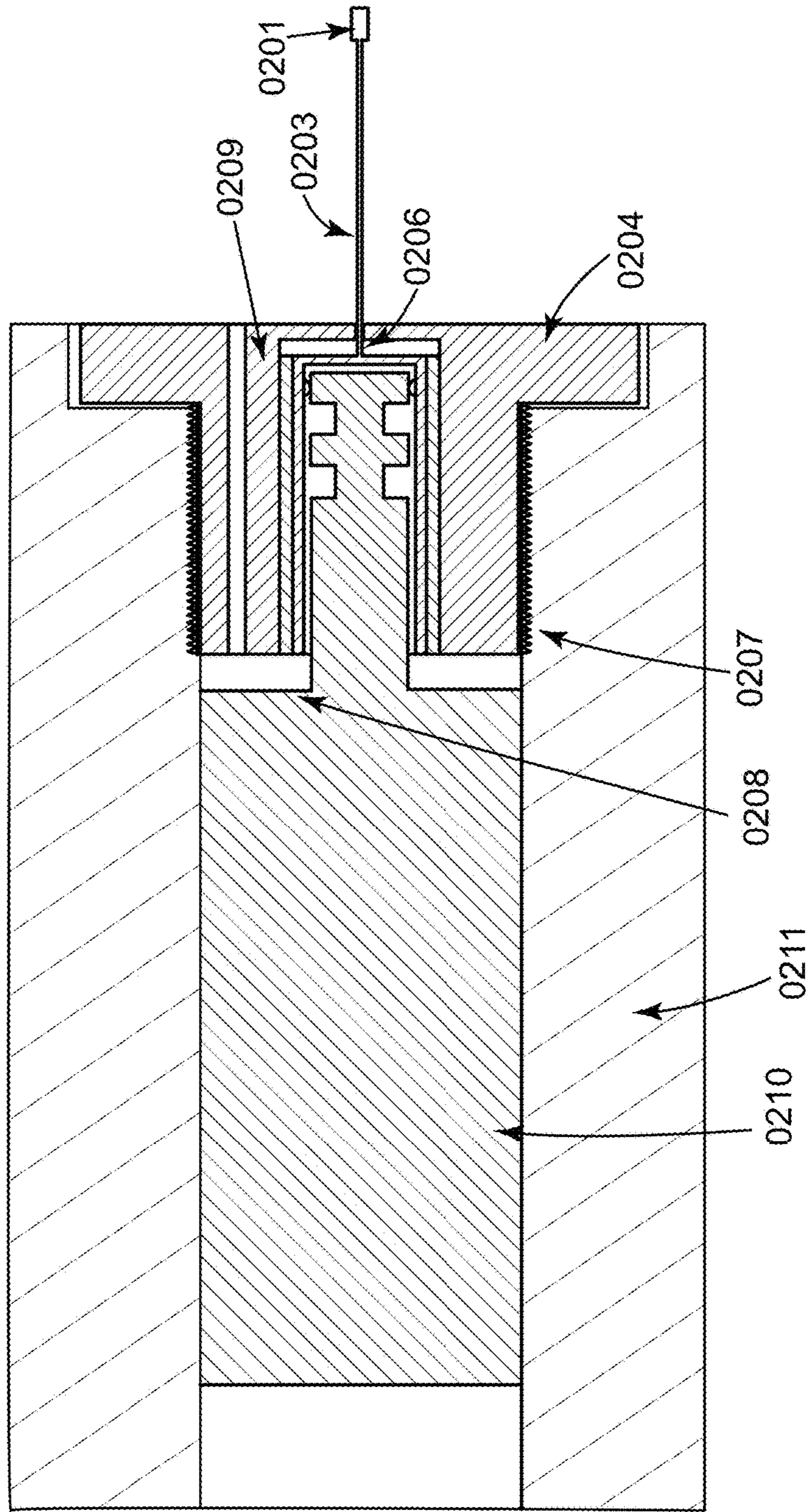


FIG. 3b

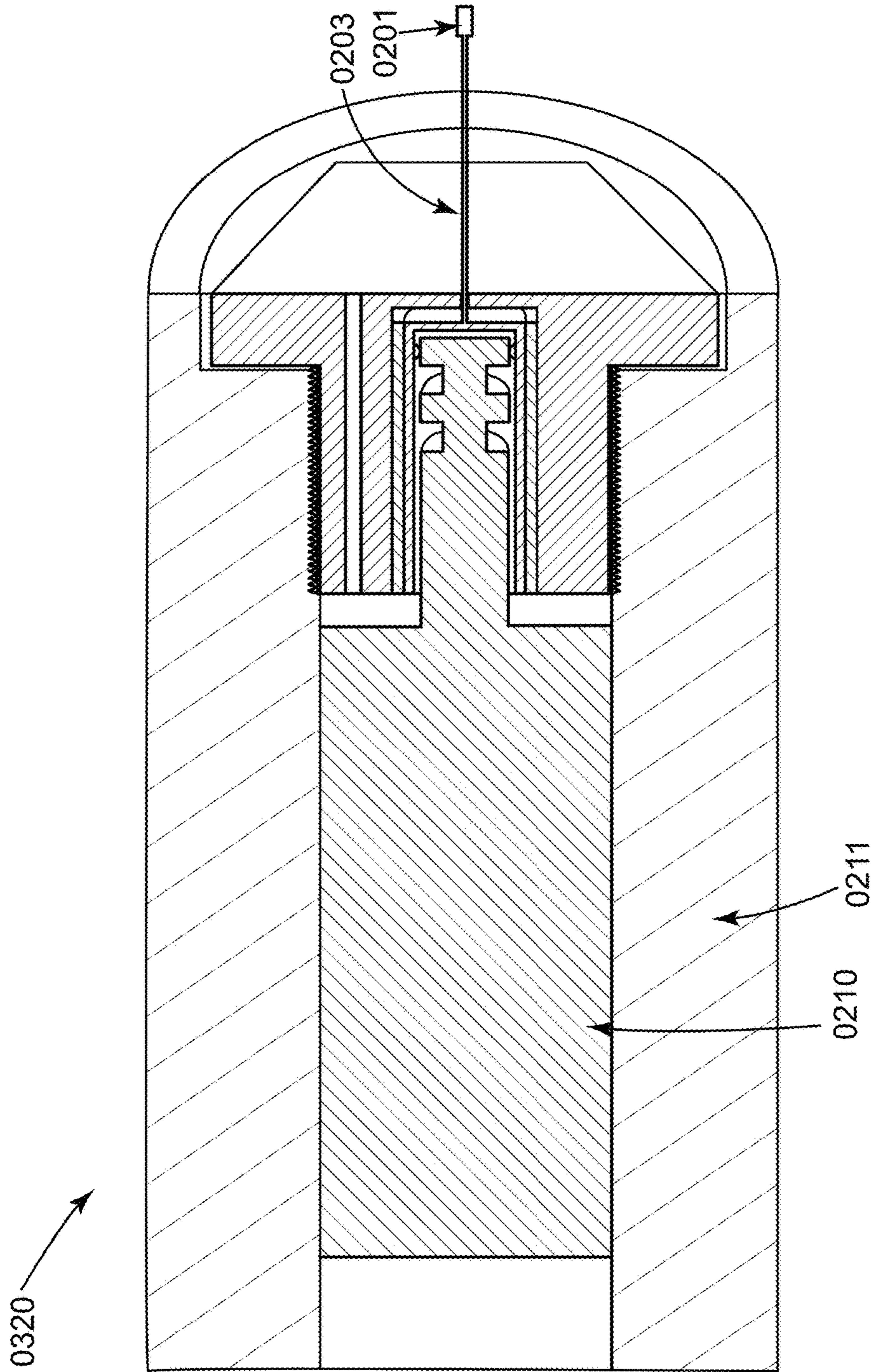


FIG. 3c

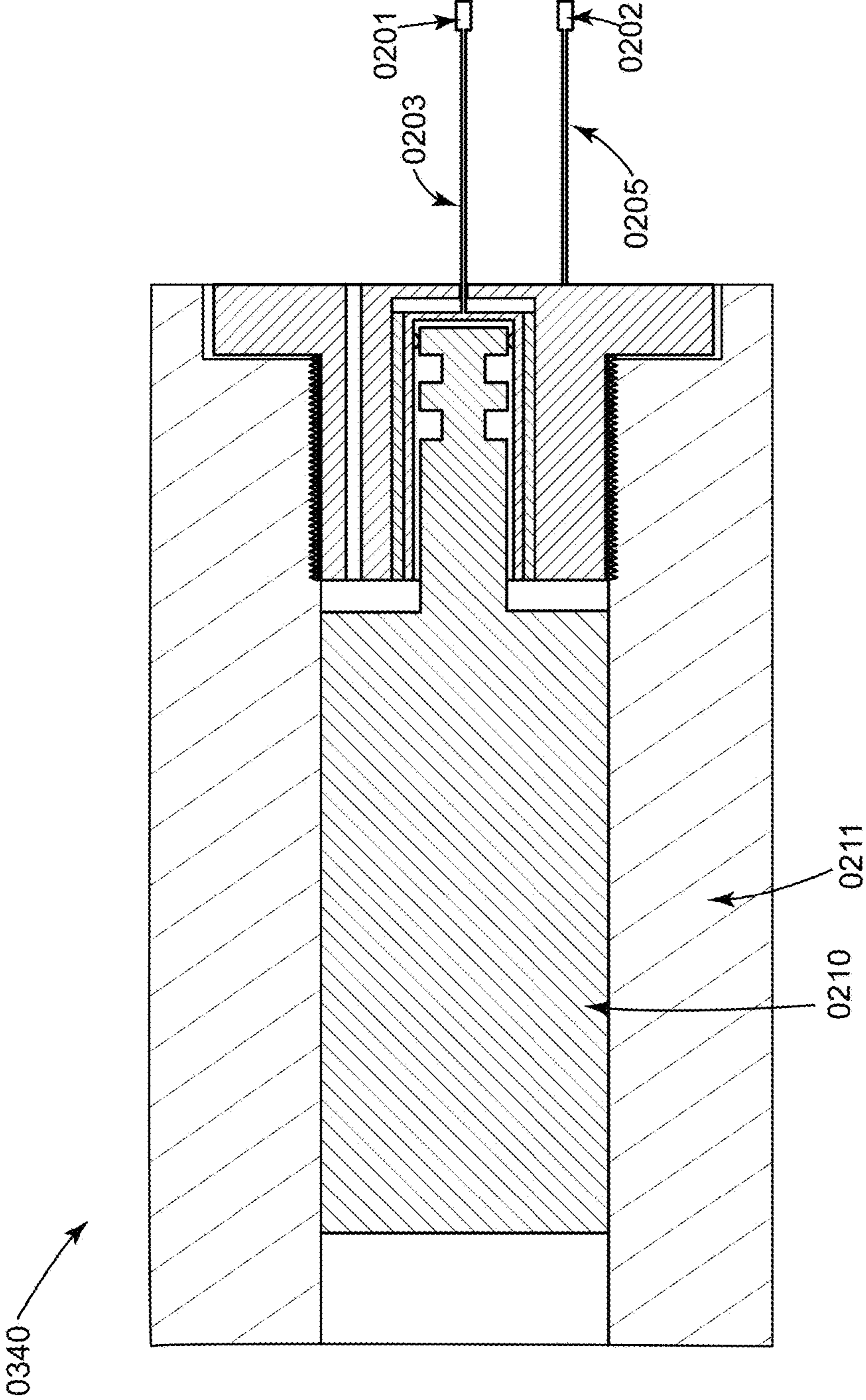


FIG. 3d

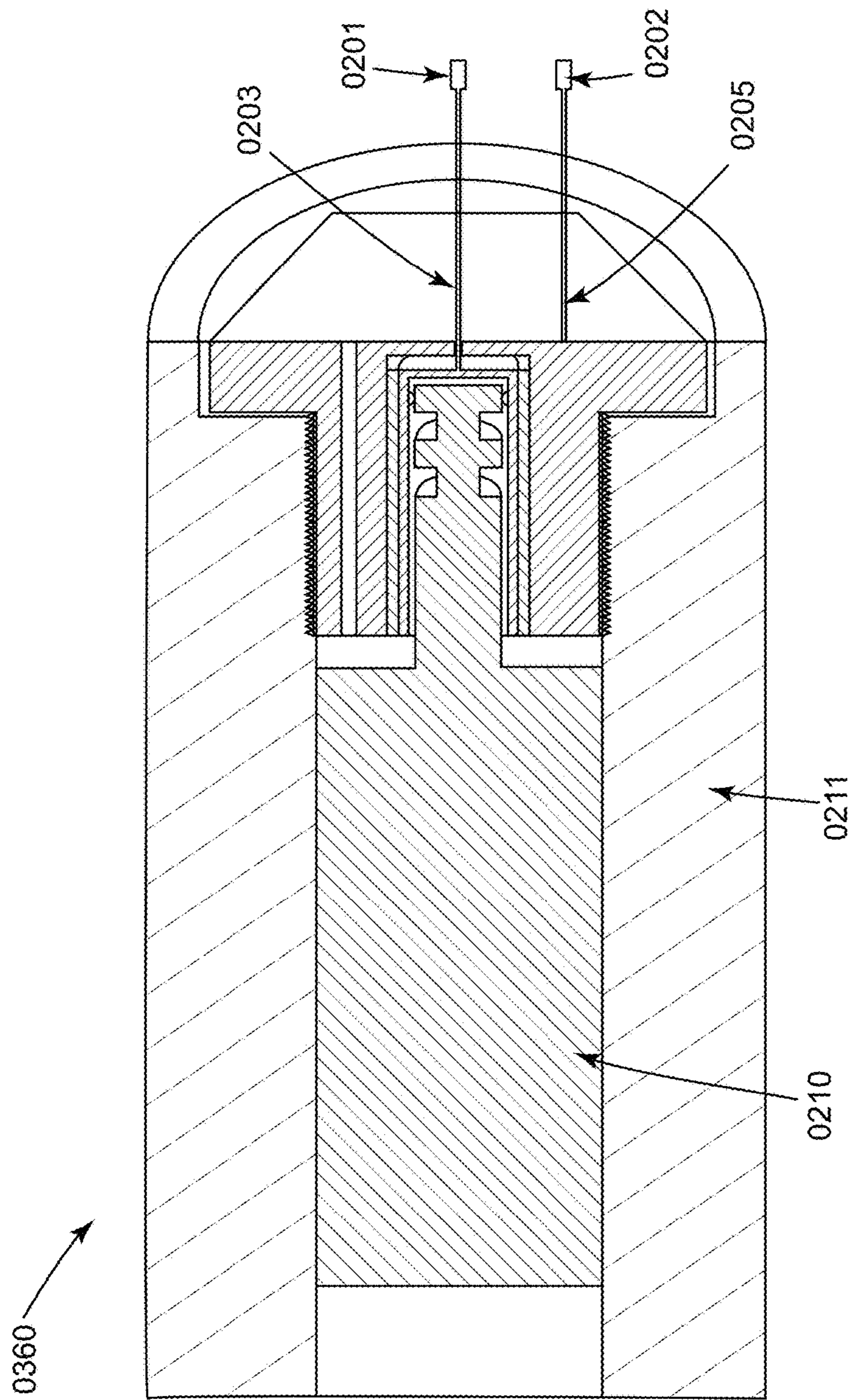
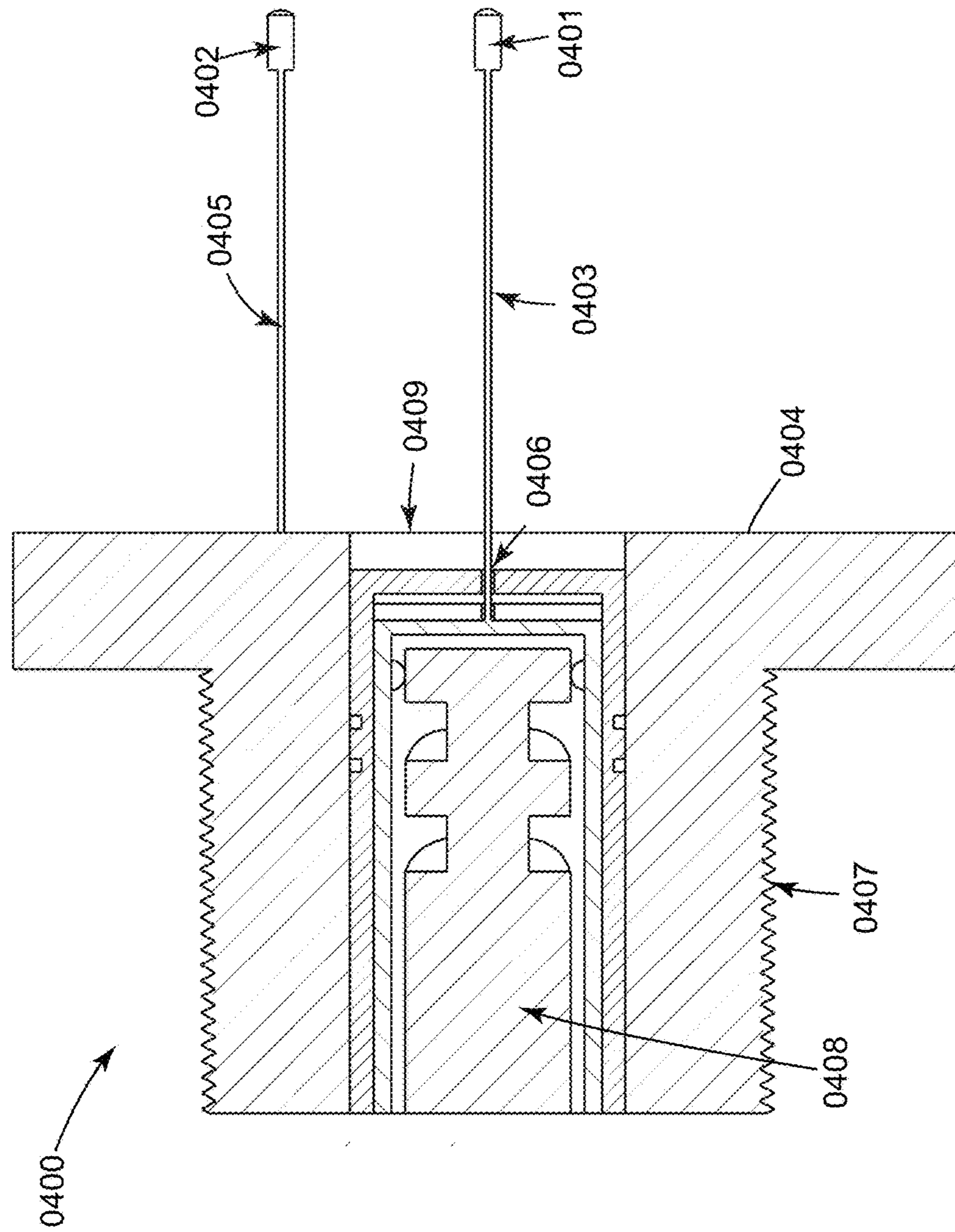
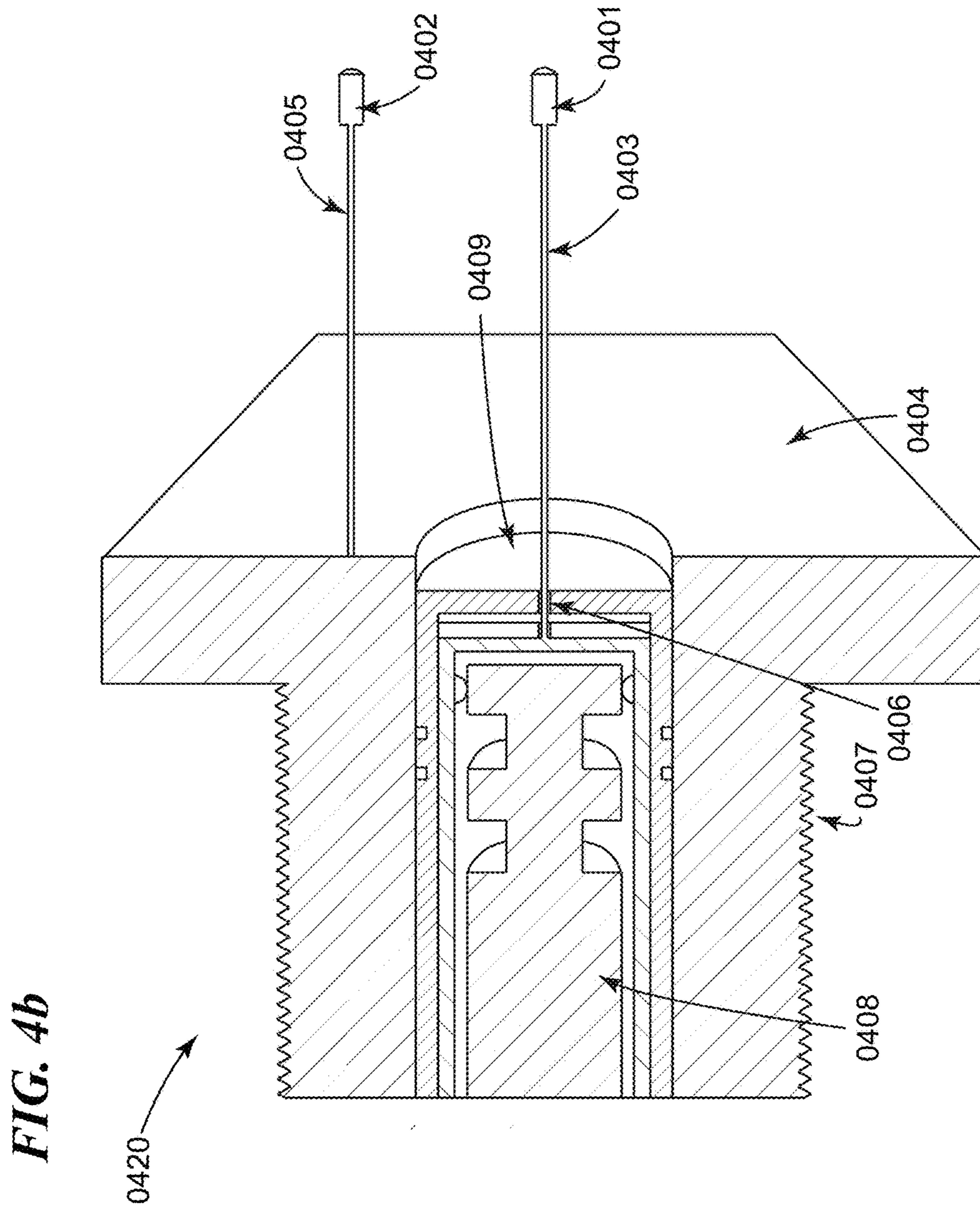
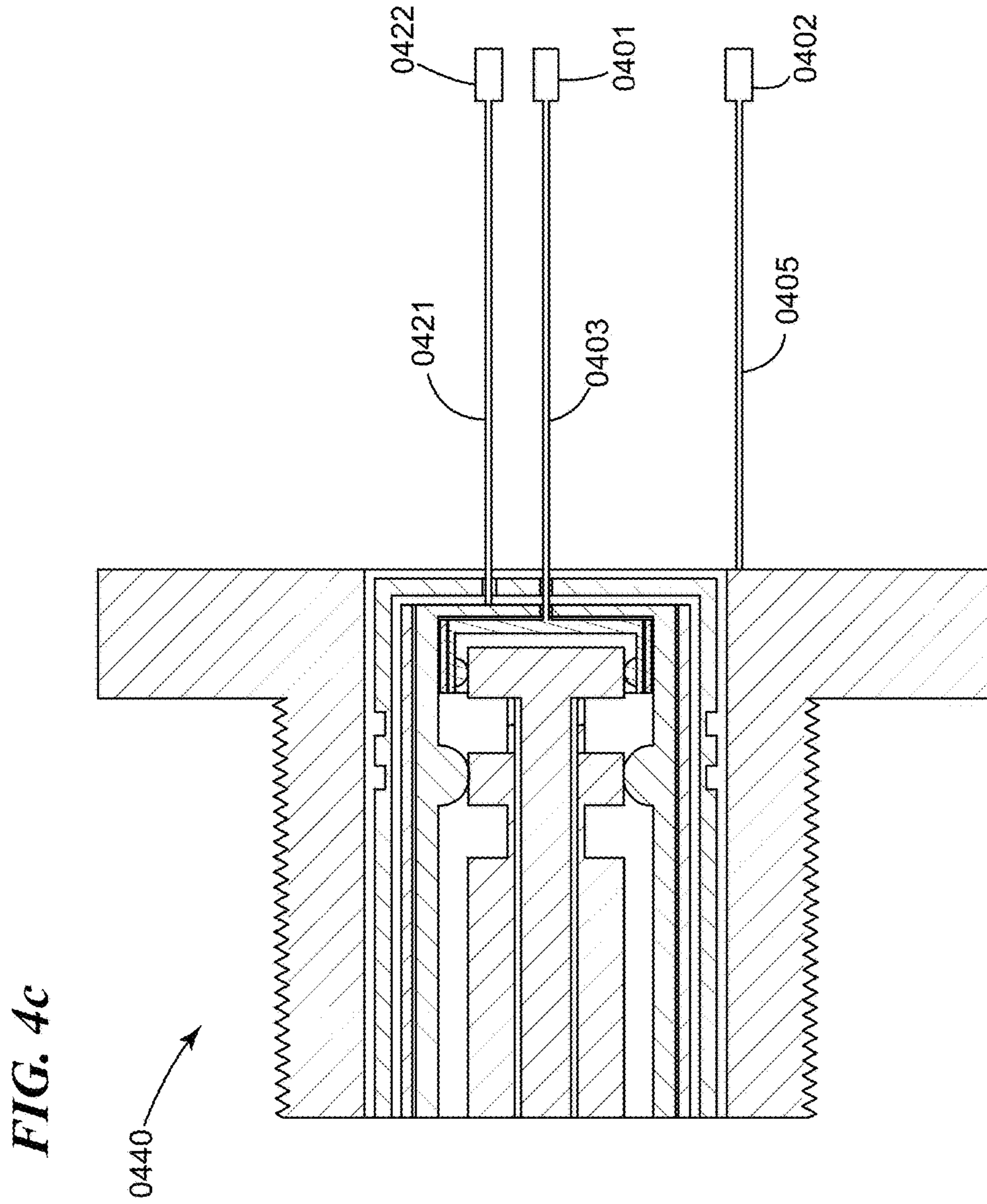


FIG. 4a







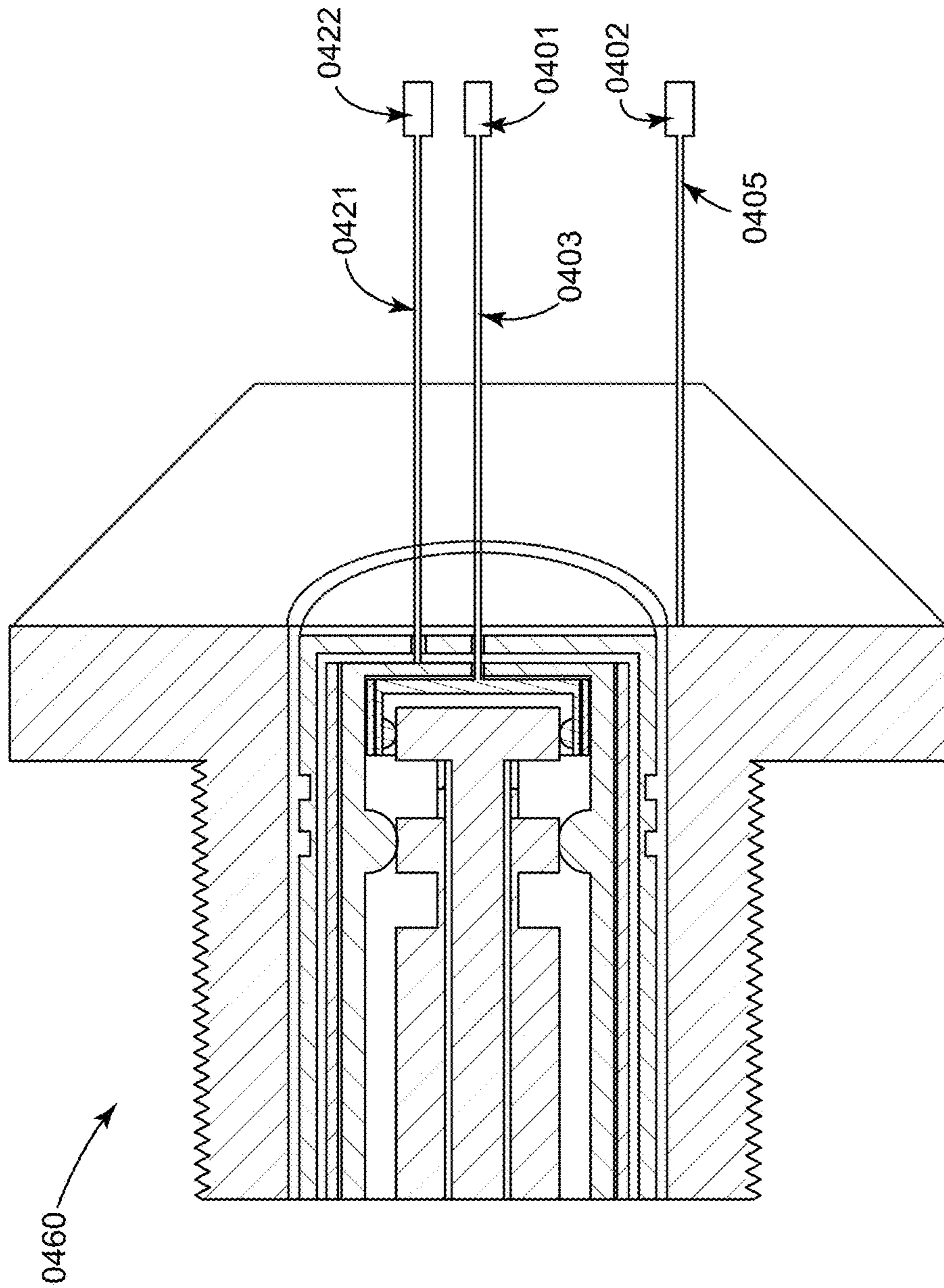


FIG. 4d

FIG. 5

0500

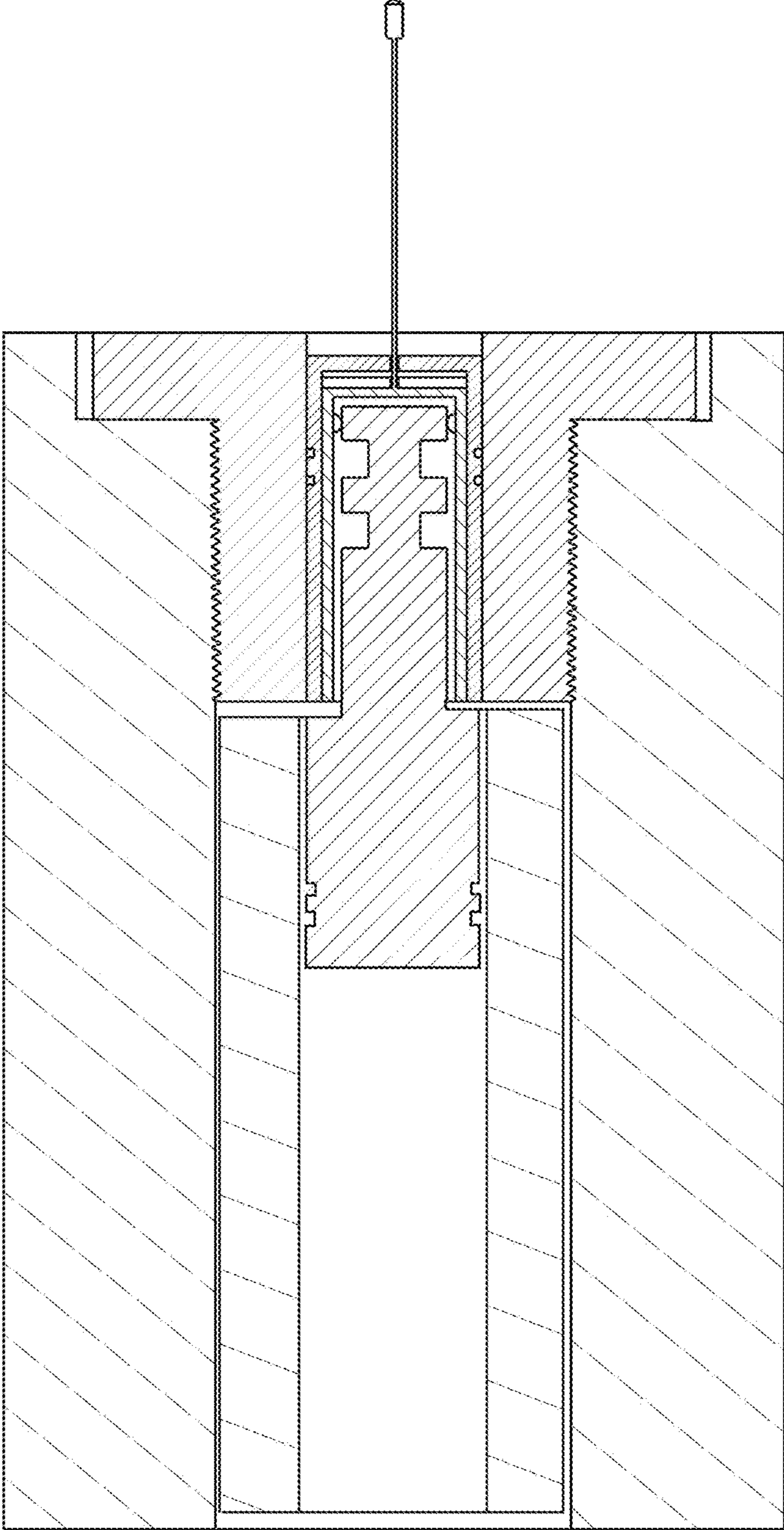


FIG. 5a

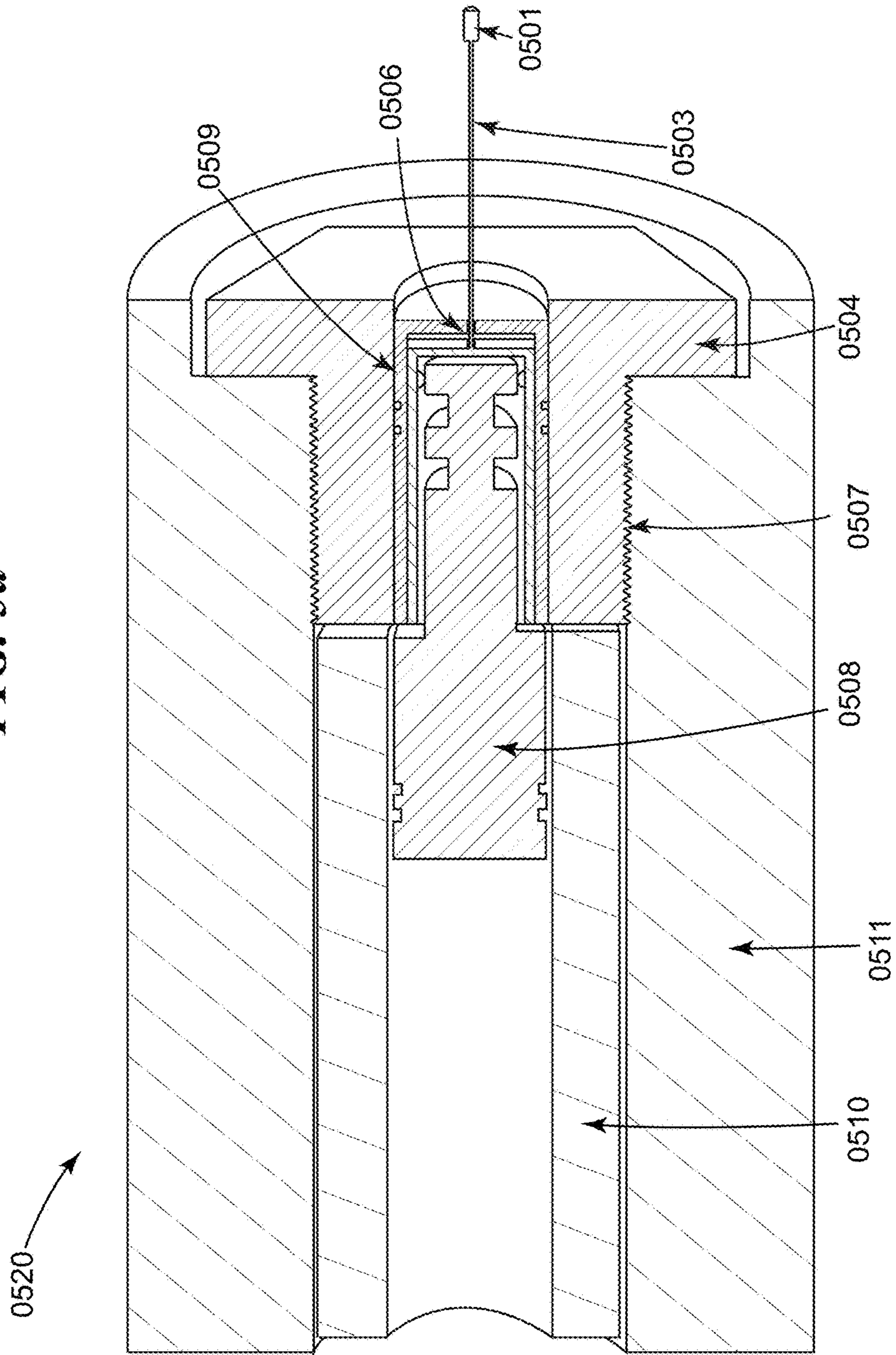


FIG. 6

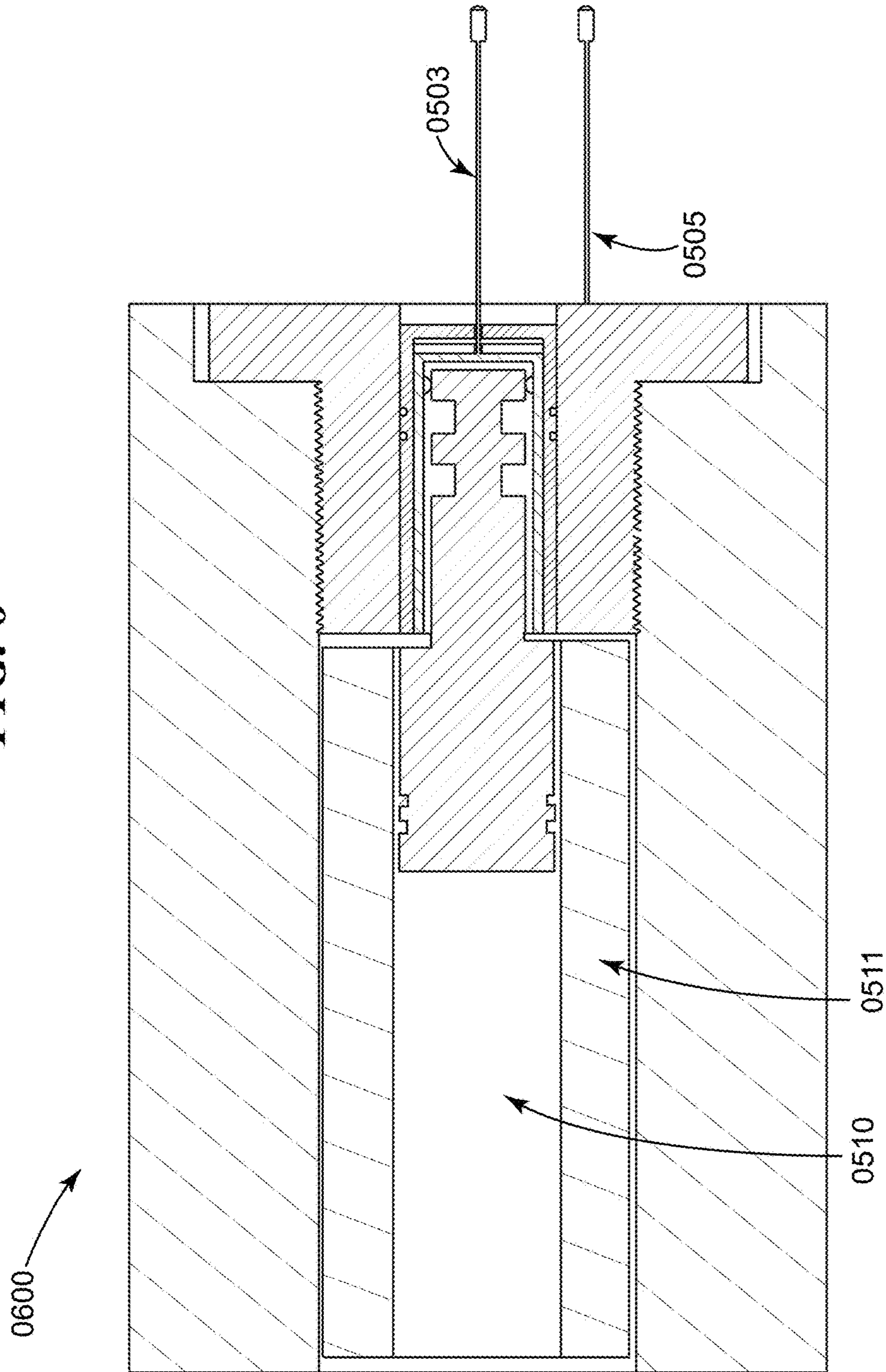


FIG. 6a

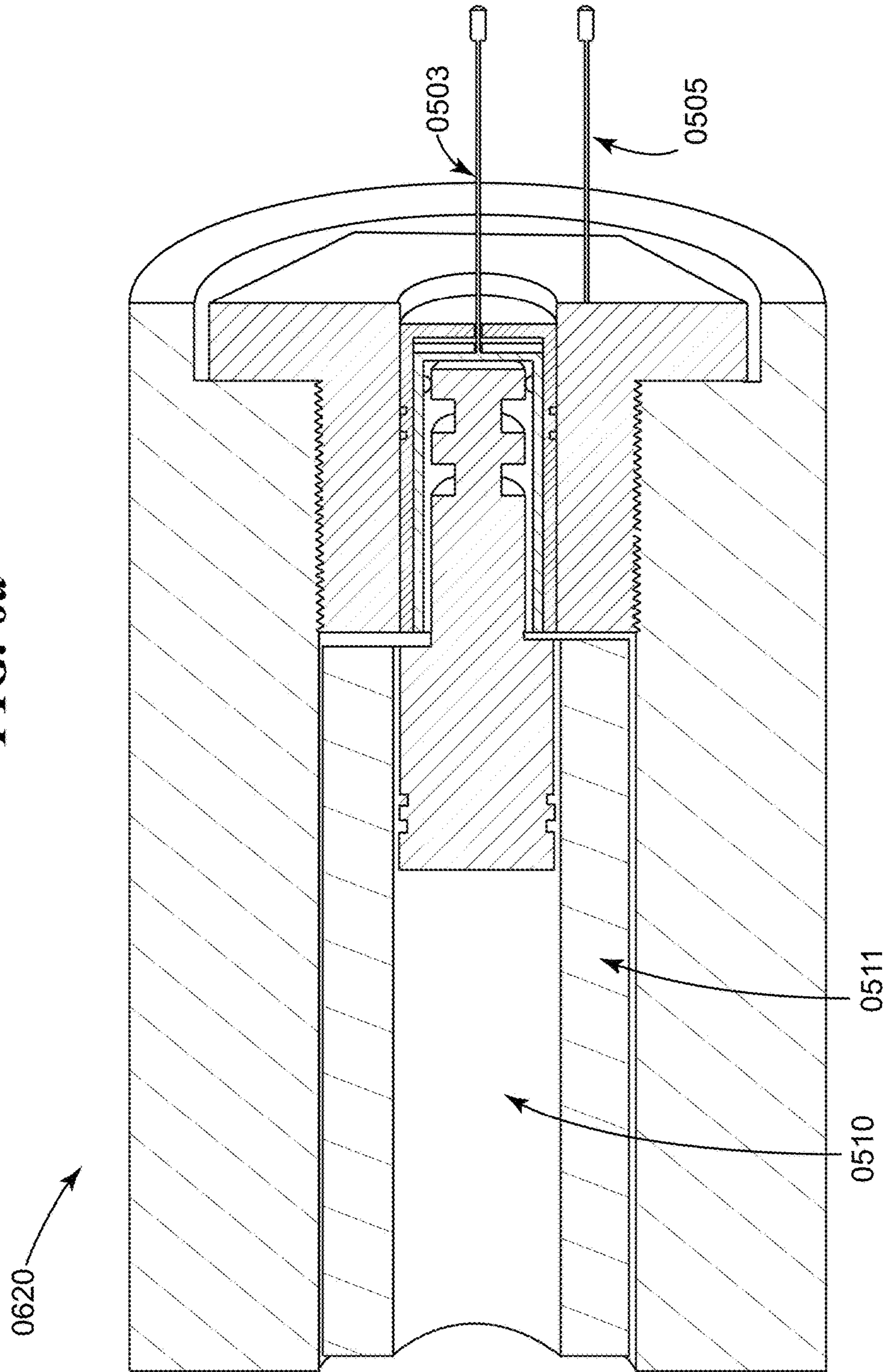


FIG. 7

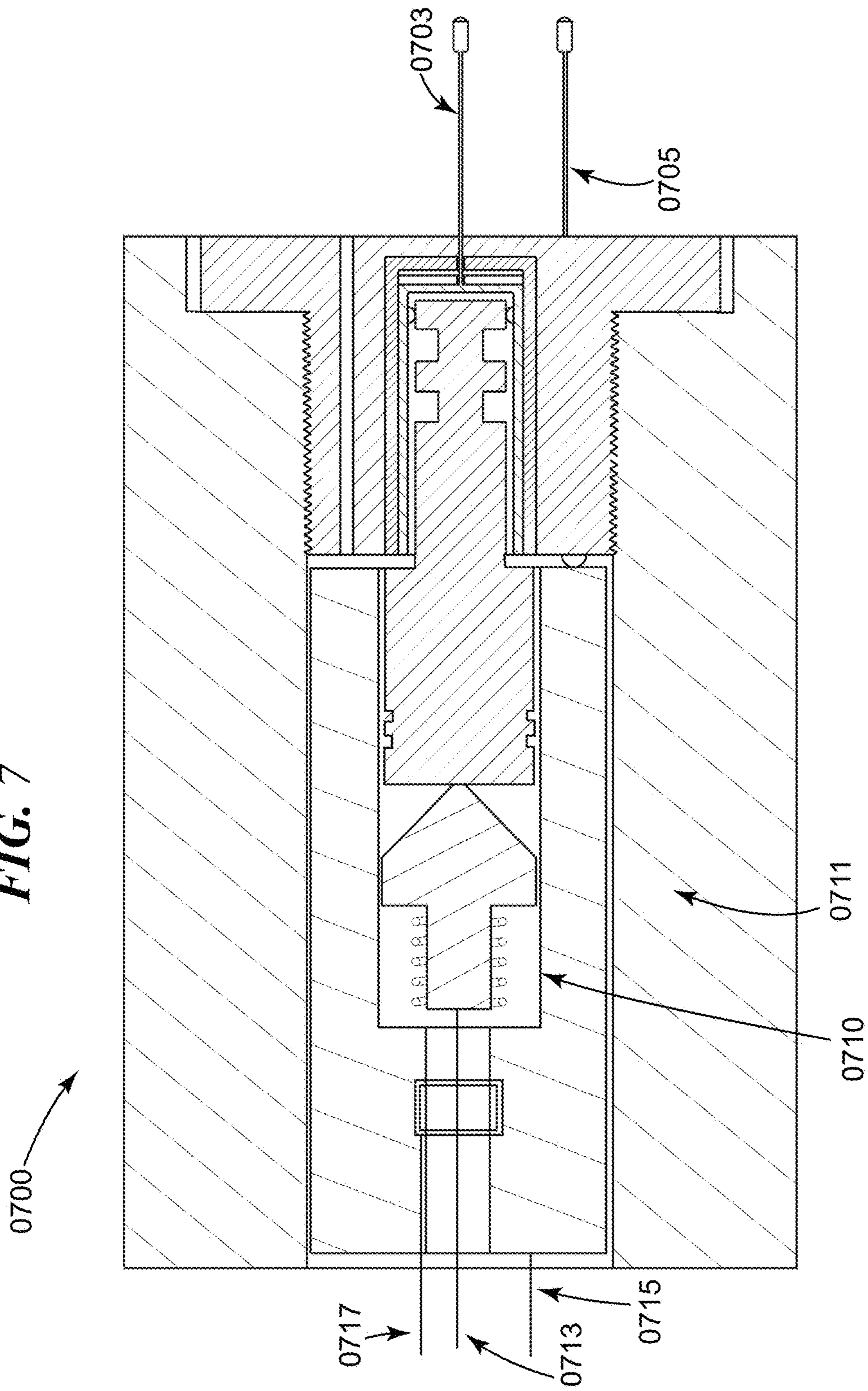


FIG. 7a

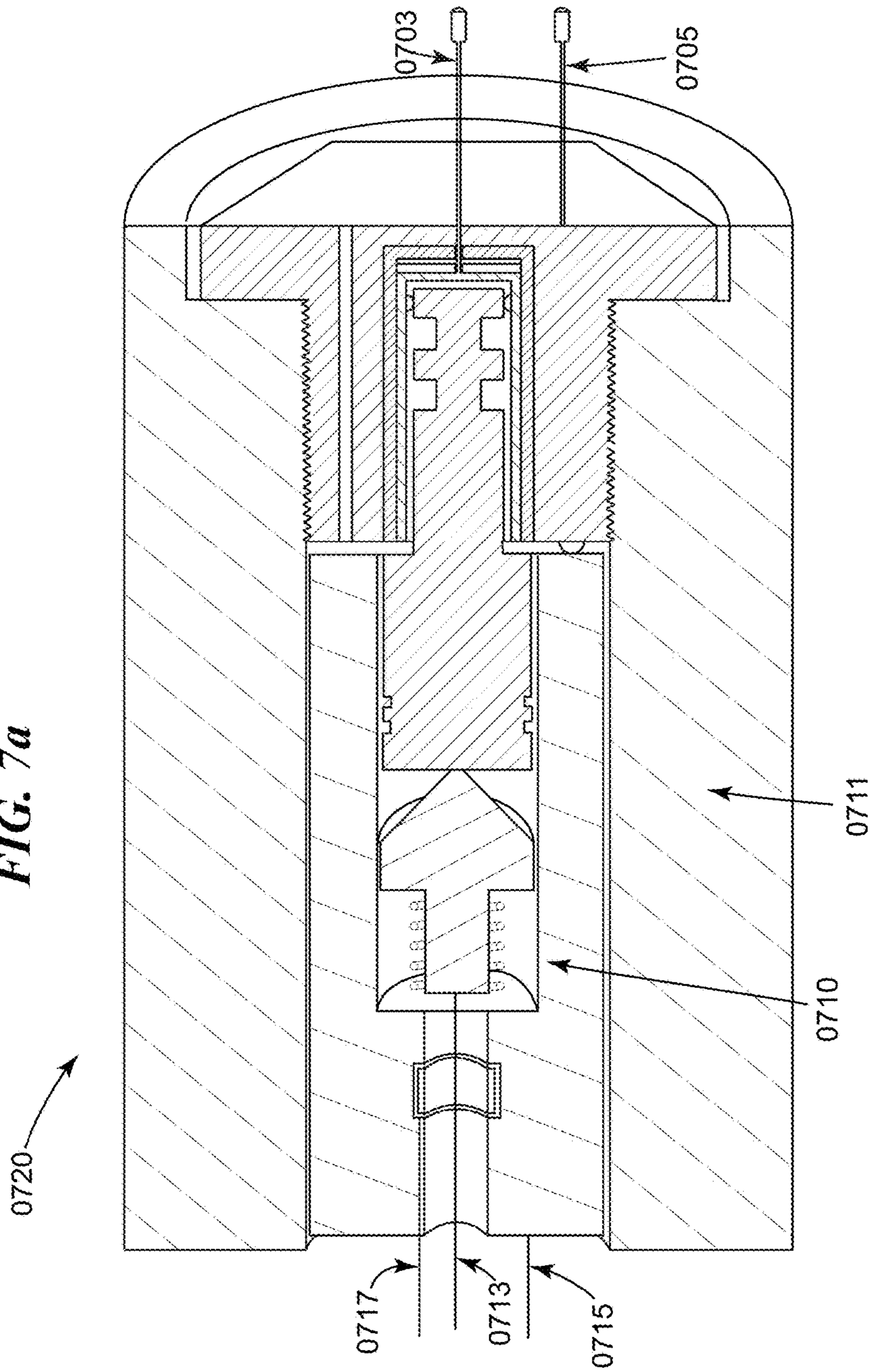


FIG. 8

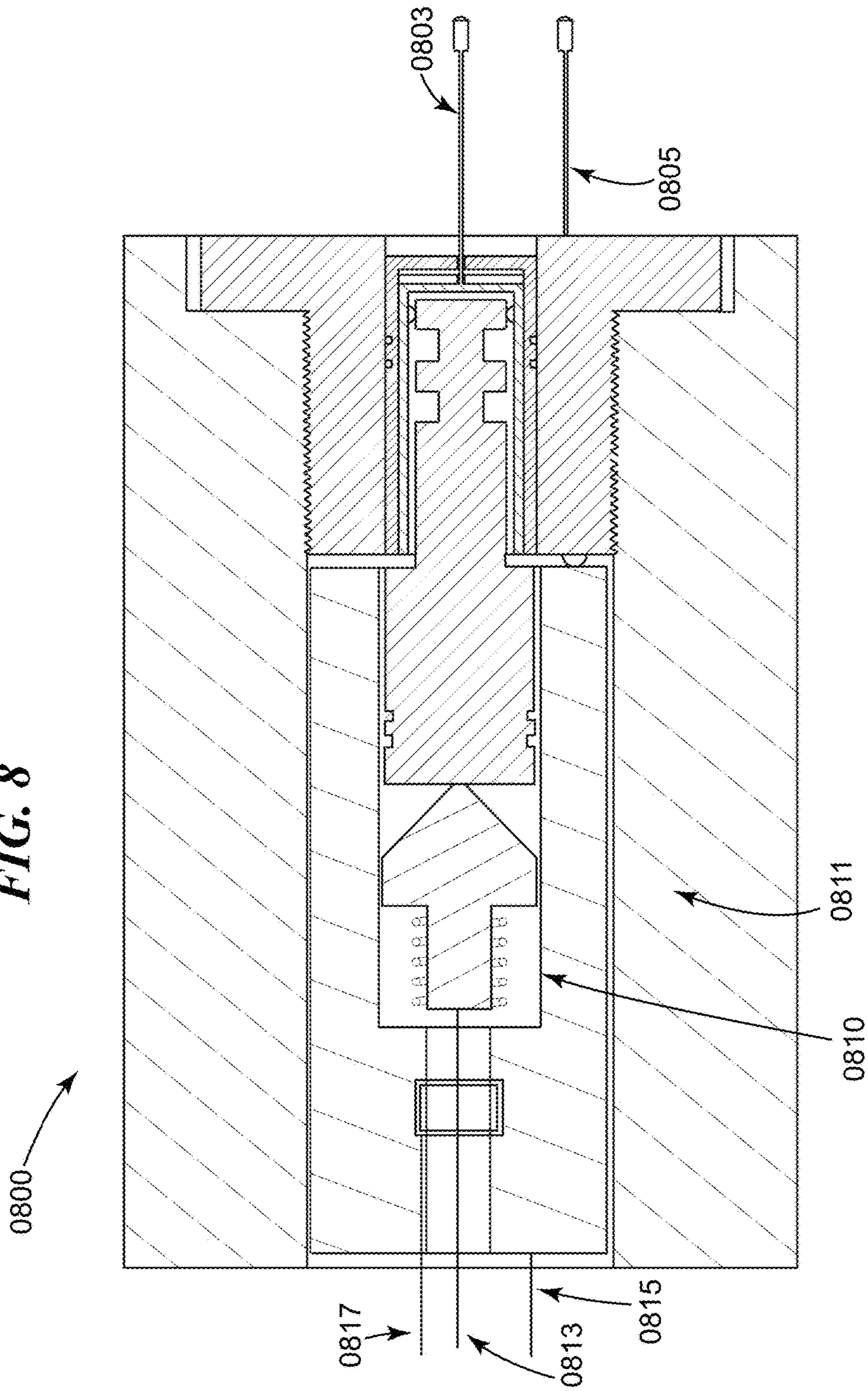
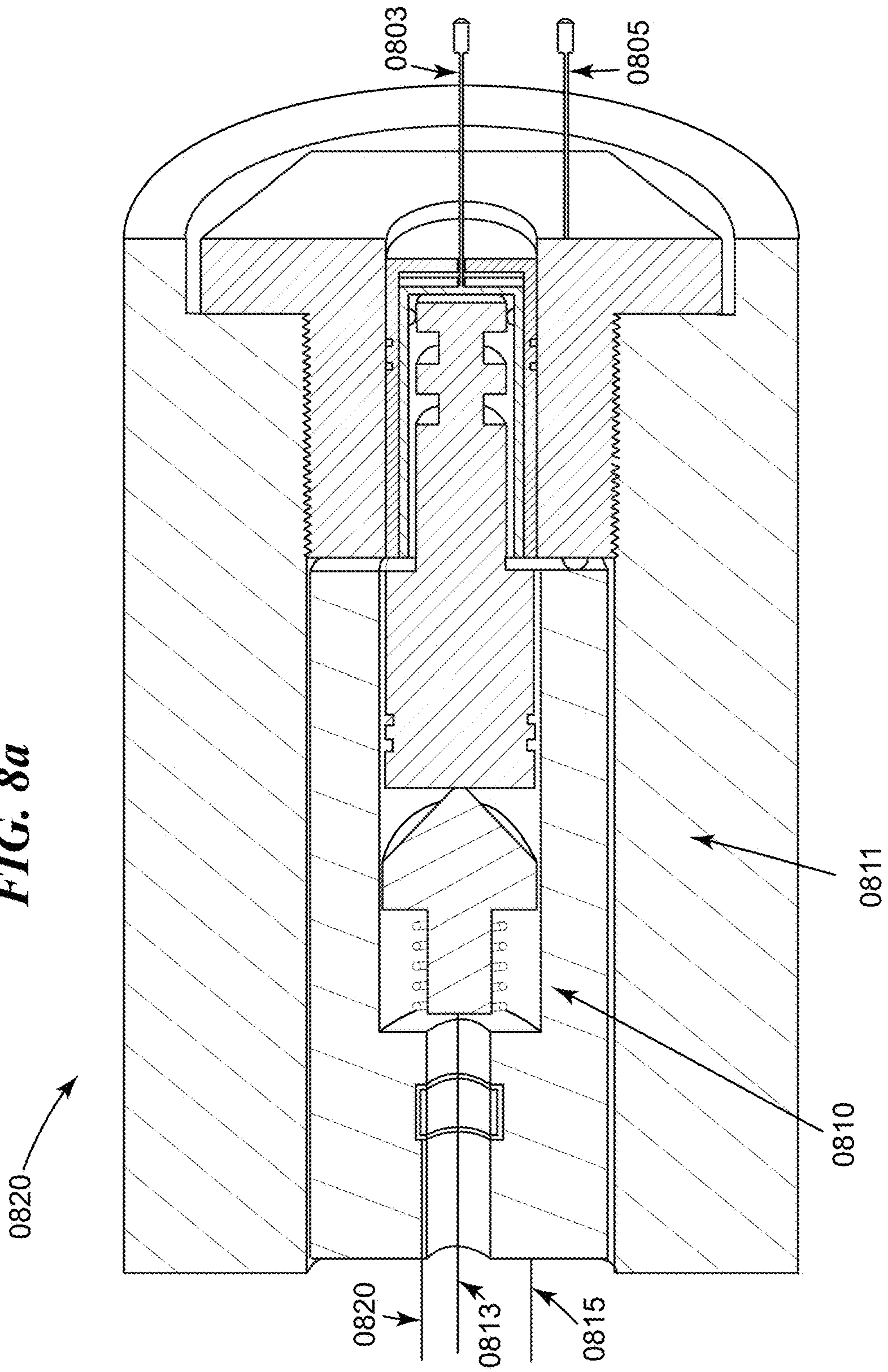


FIG. 8a



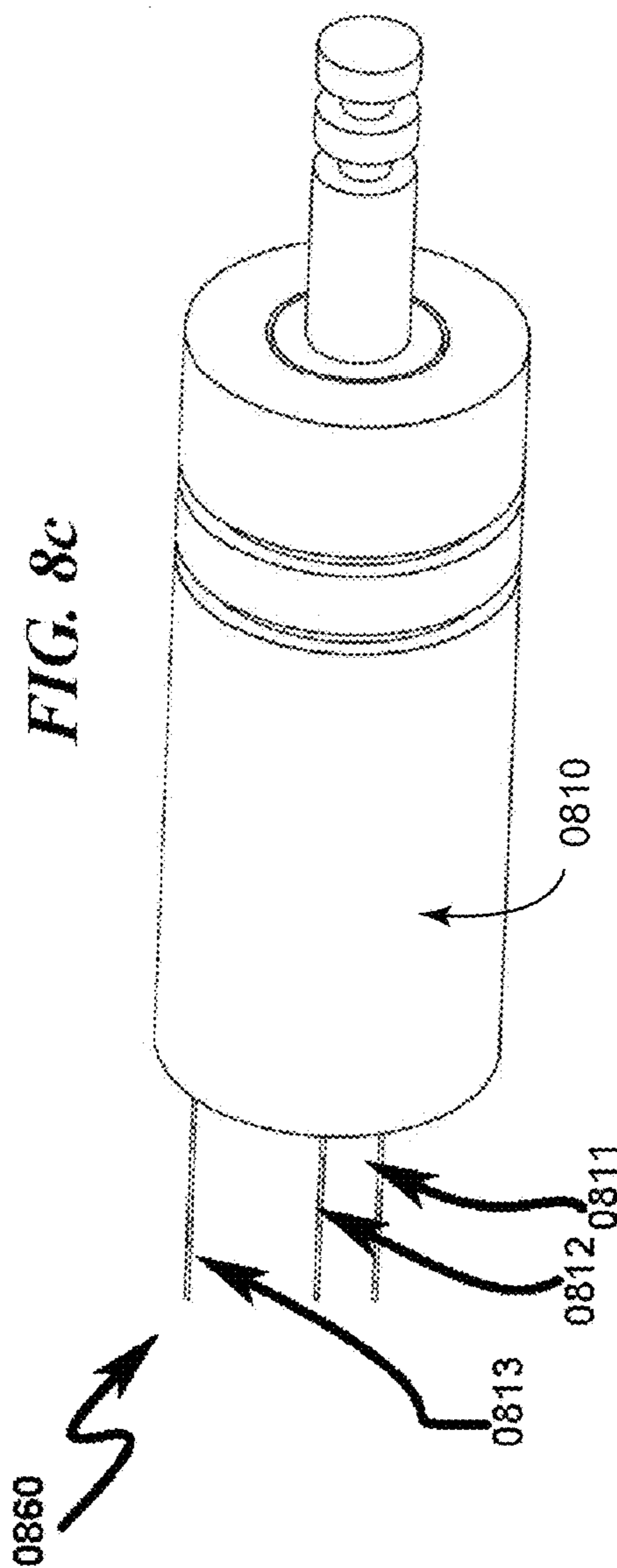
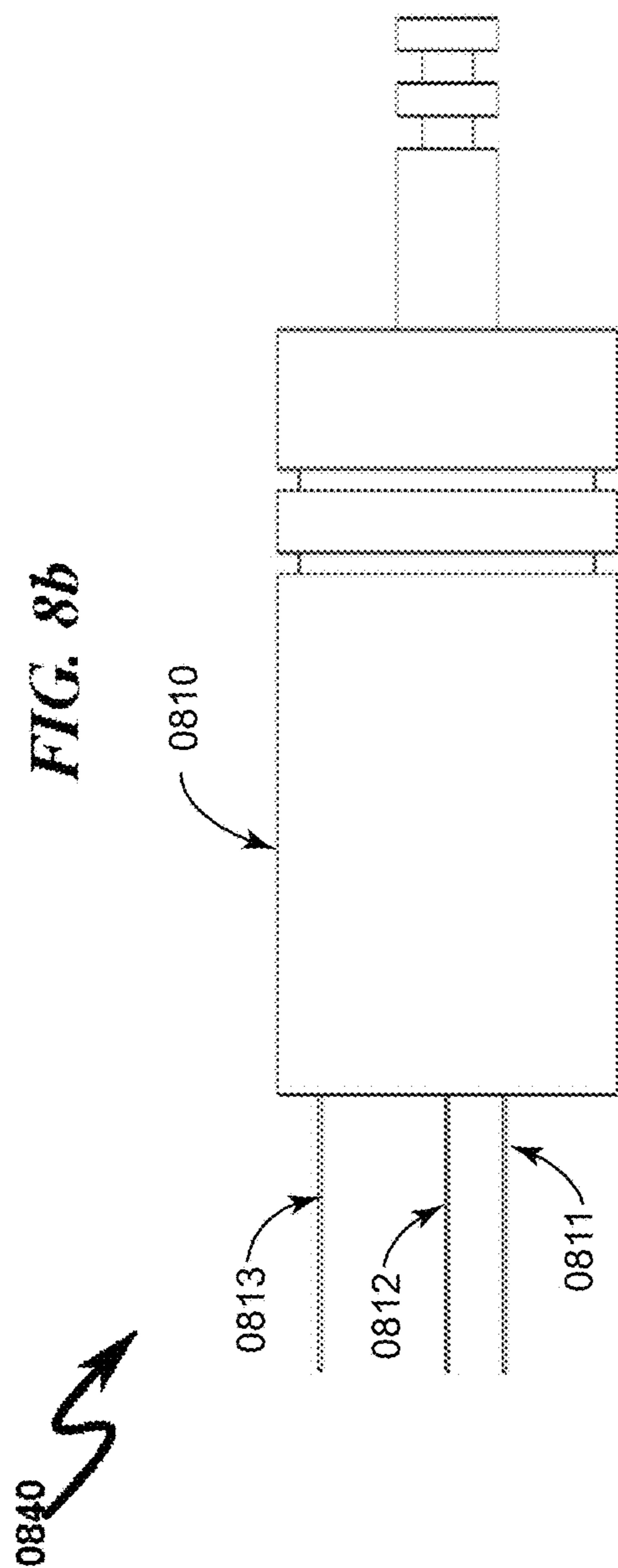


FIG. 8d

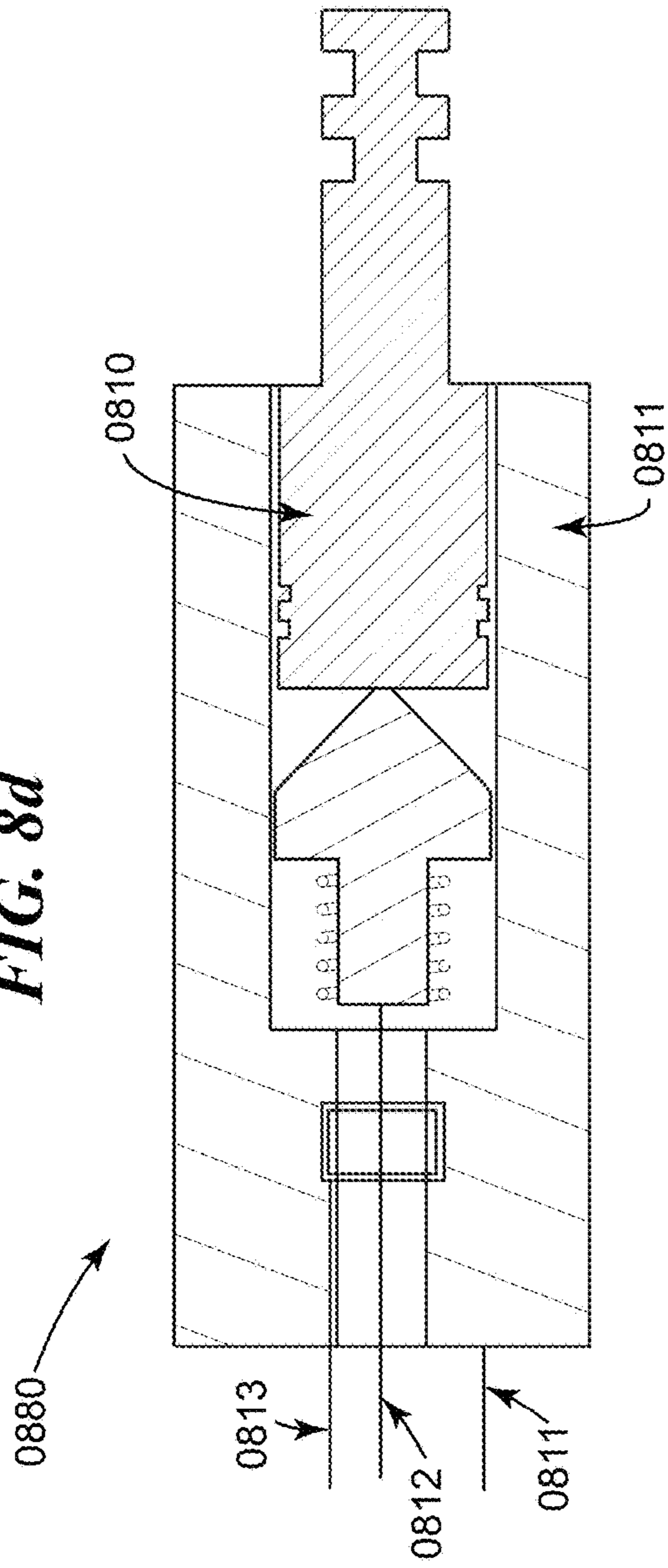


FIG. 8e

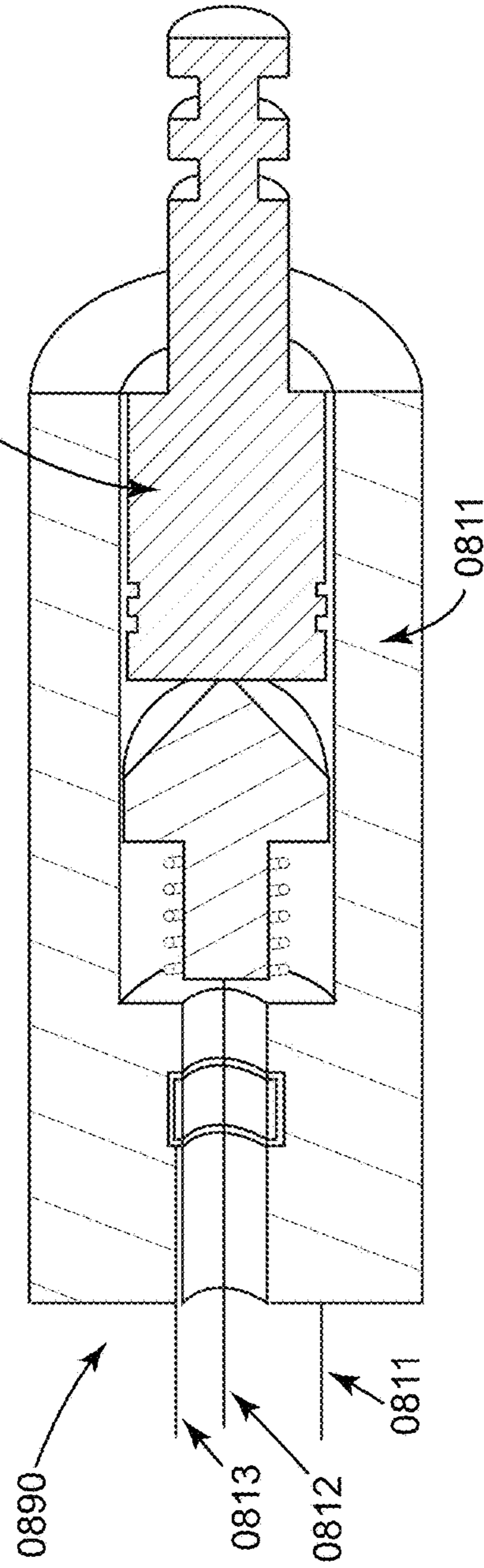


FIG. 9

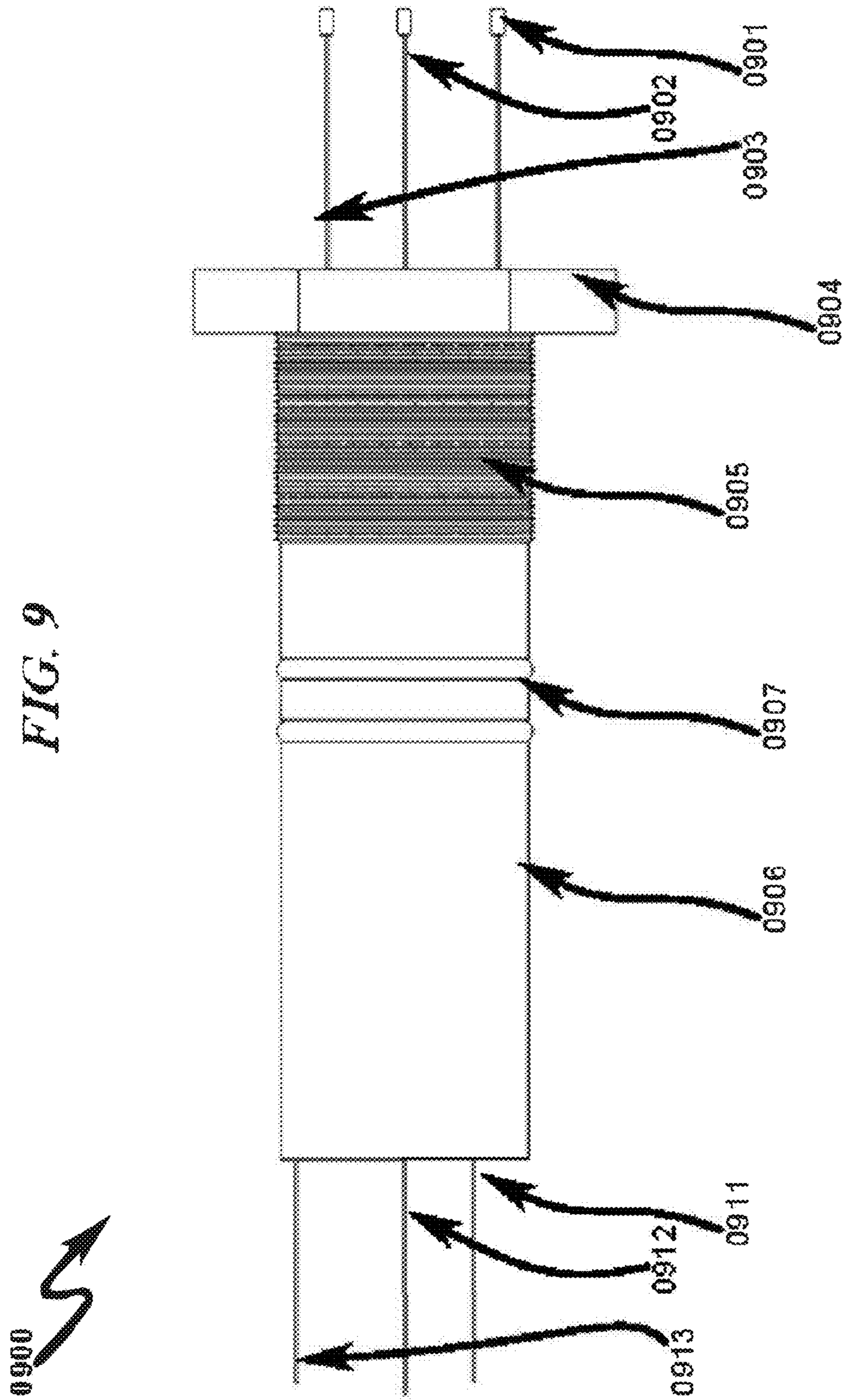
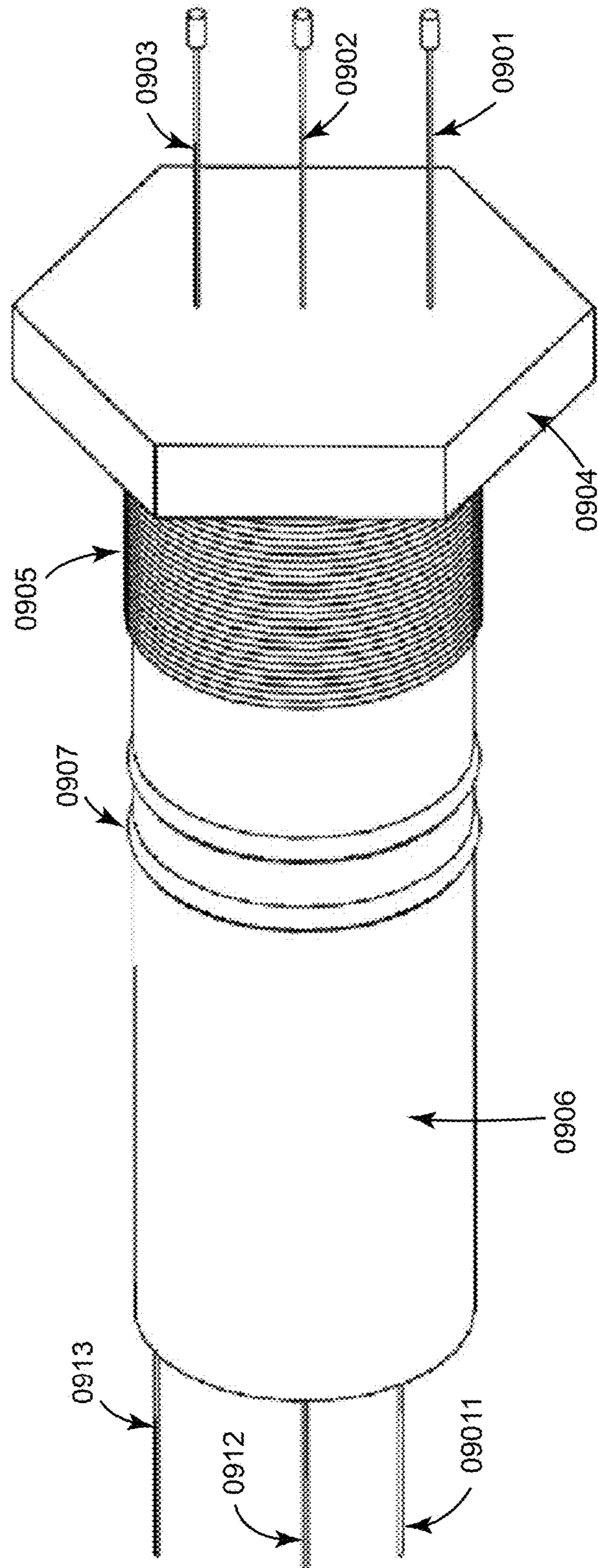


FIG. 9a

0920 



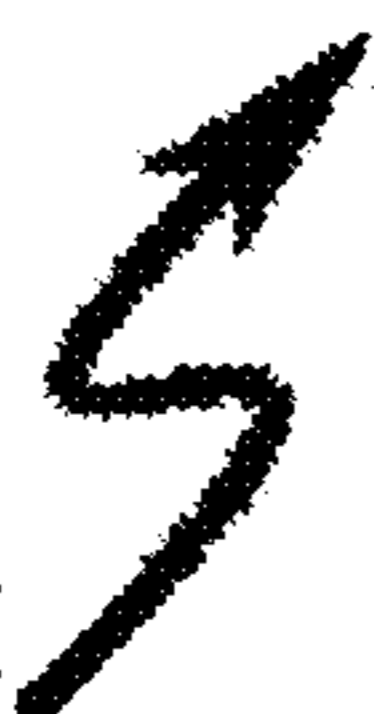
1000 

FIG. 10

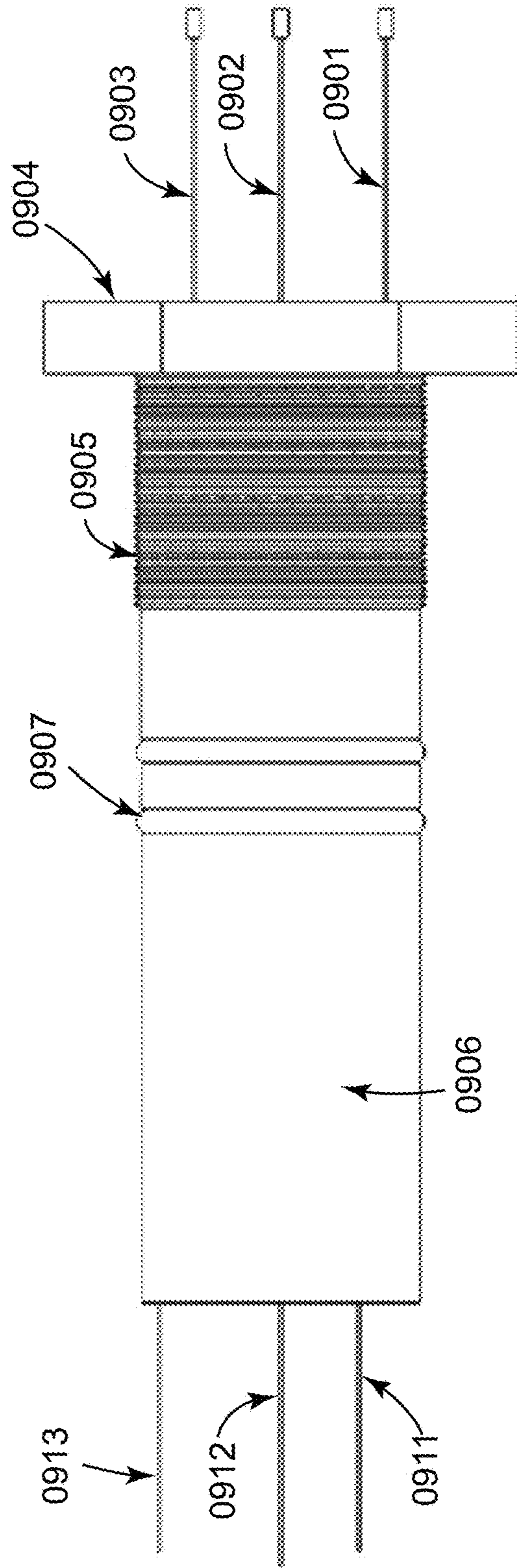


FIG. 10a

1020

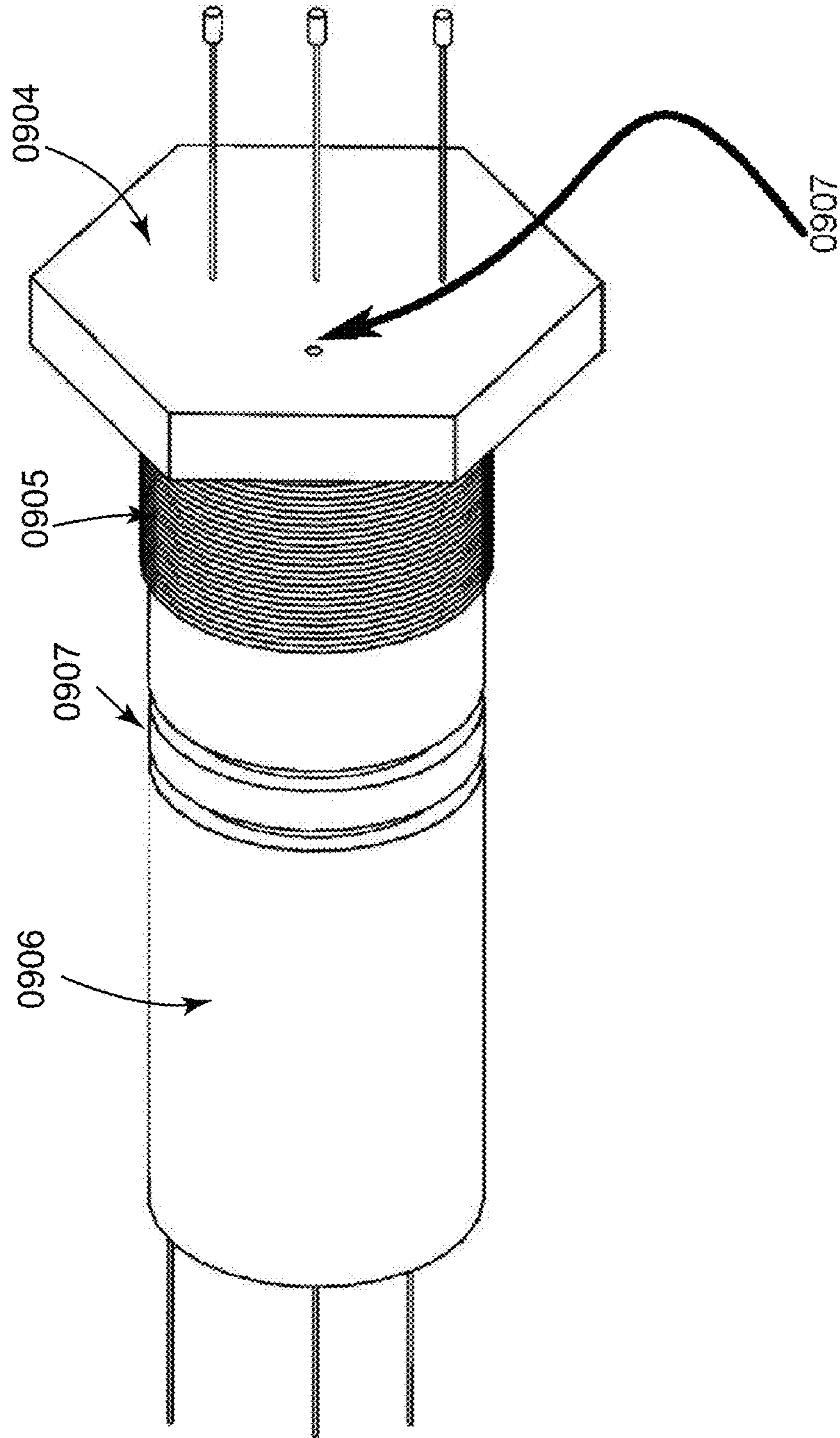
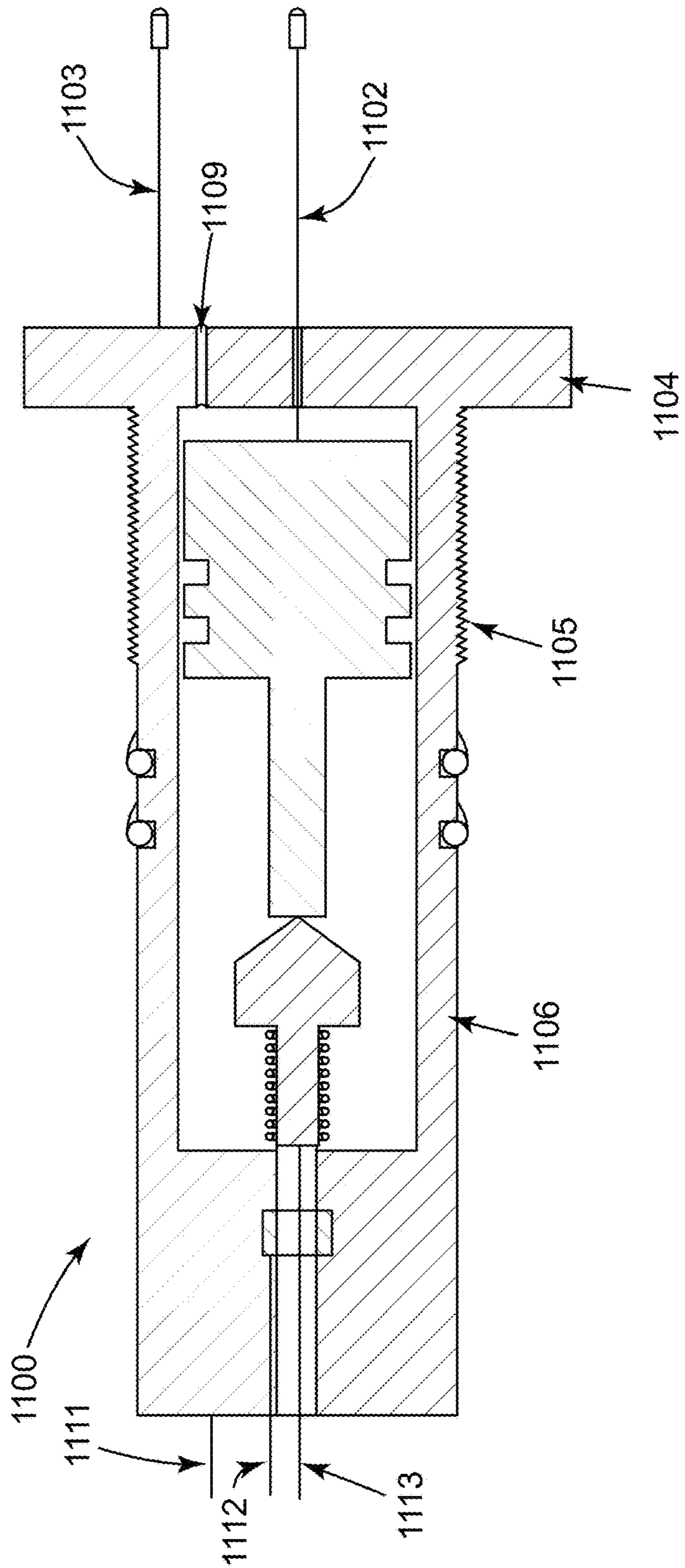


FIG. 11



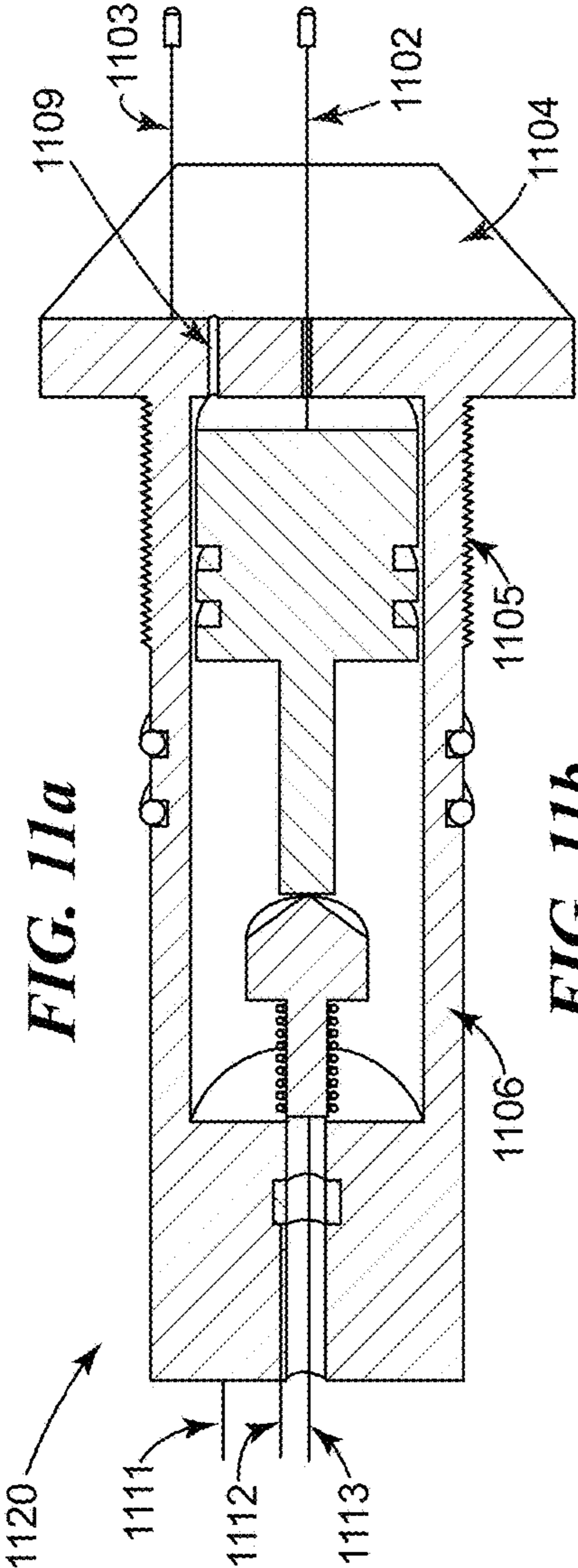


FIG. 11a

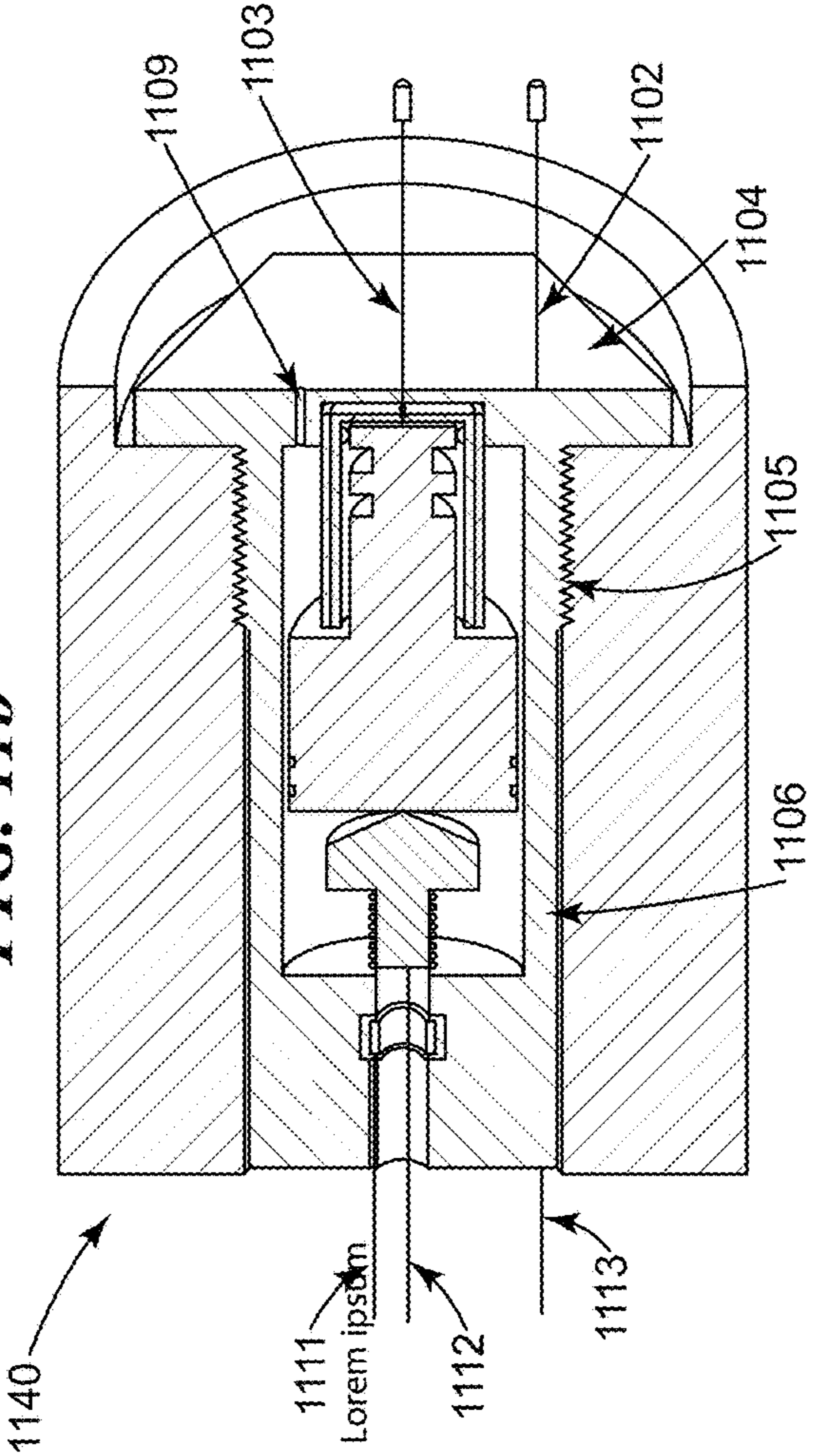


FIG. 11b

FIG. 12

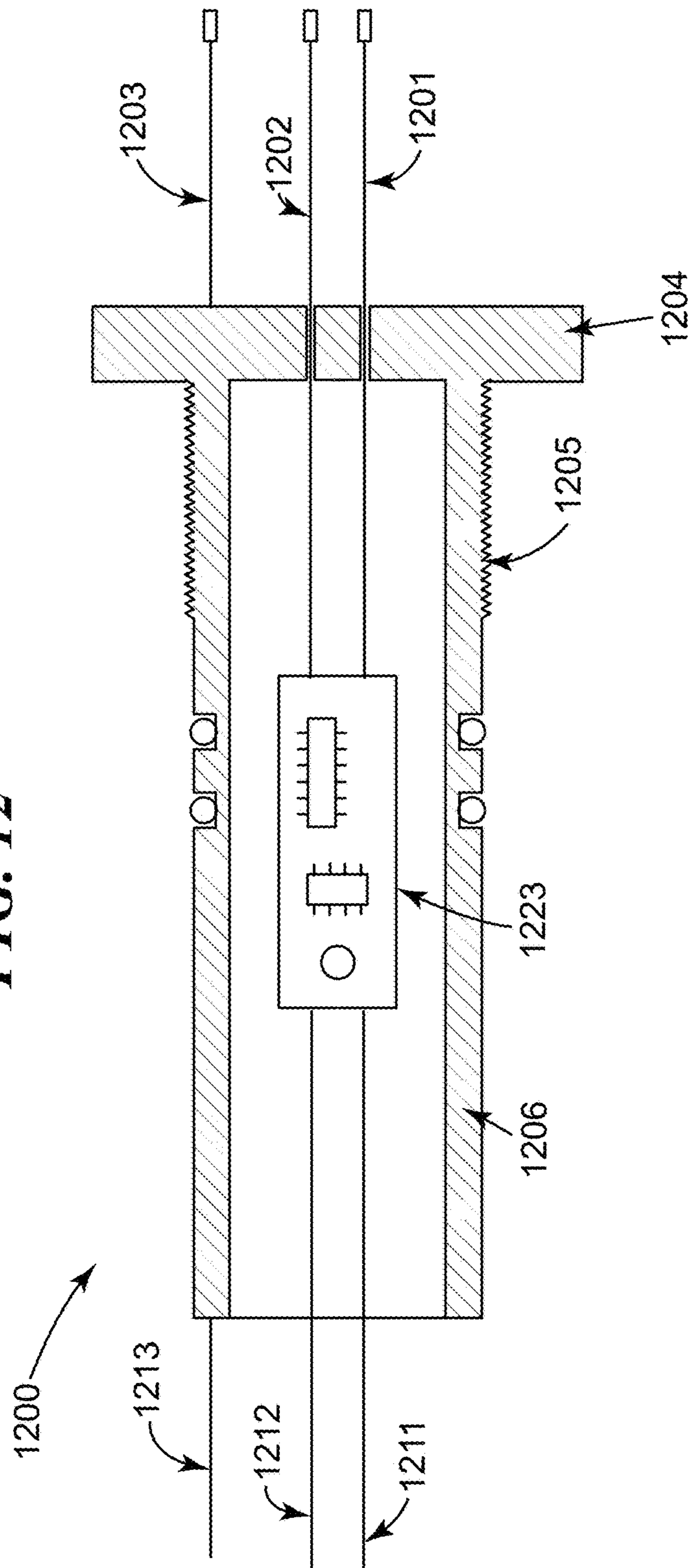


FIG. 12a

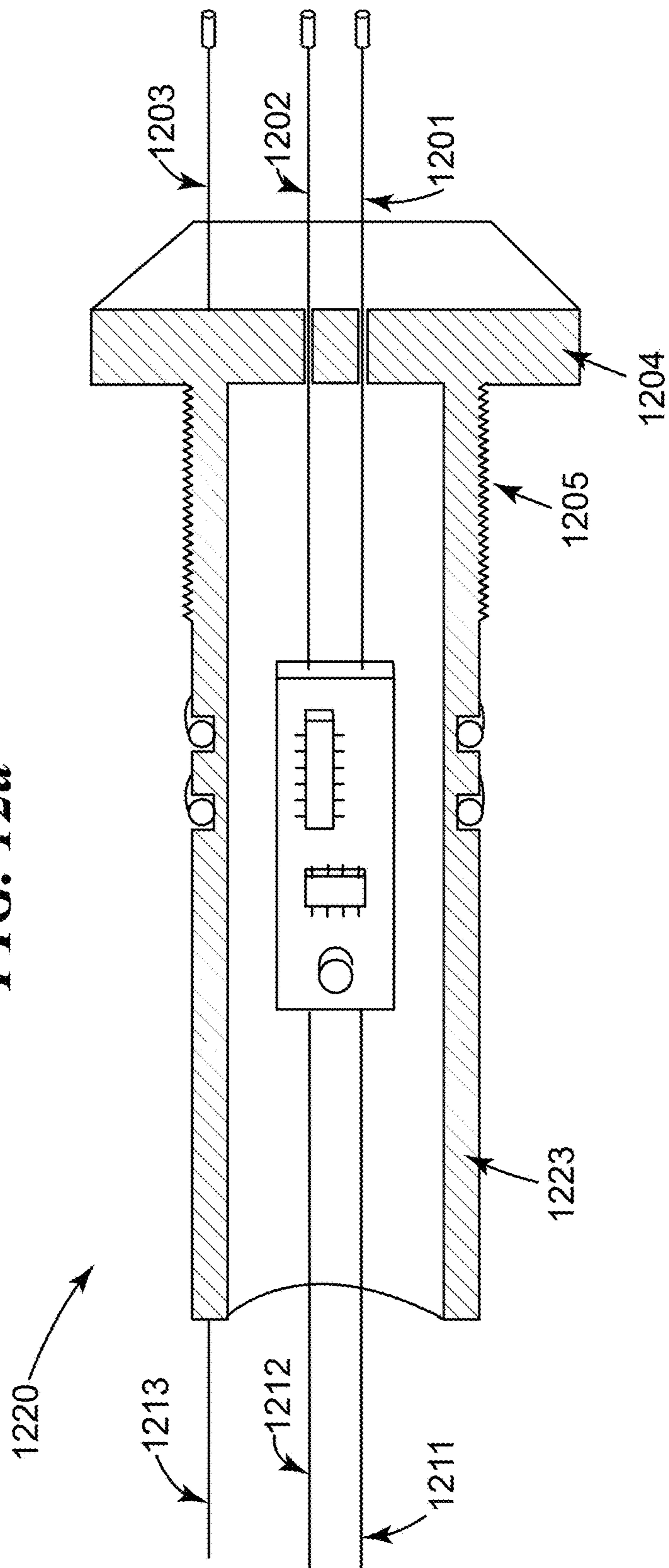


FIG. 13

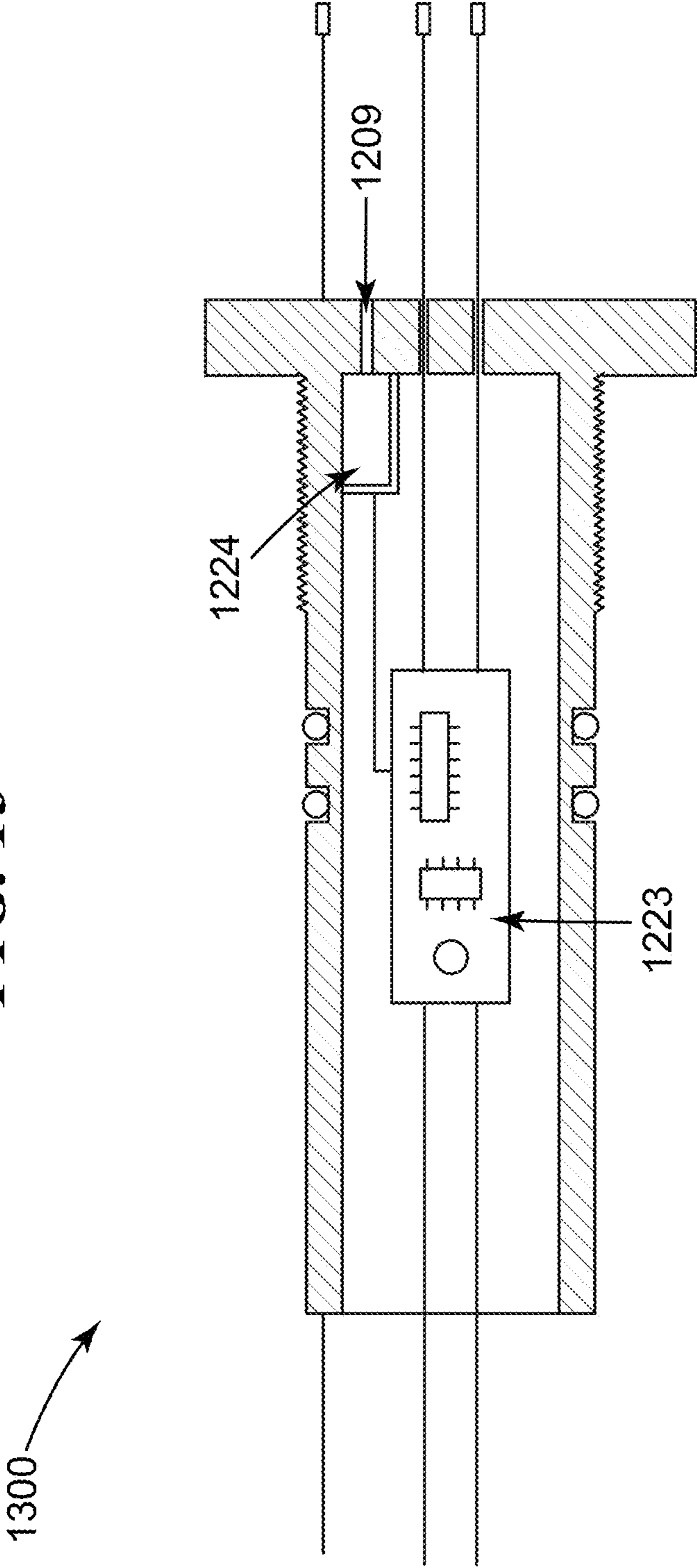


FIG. 13a

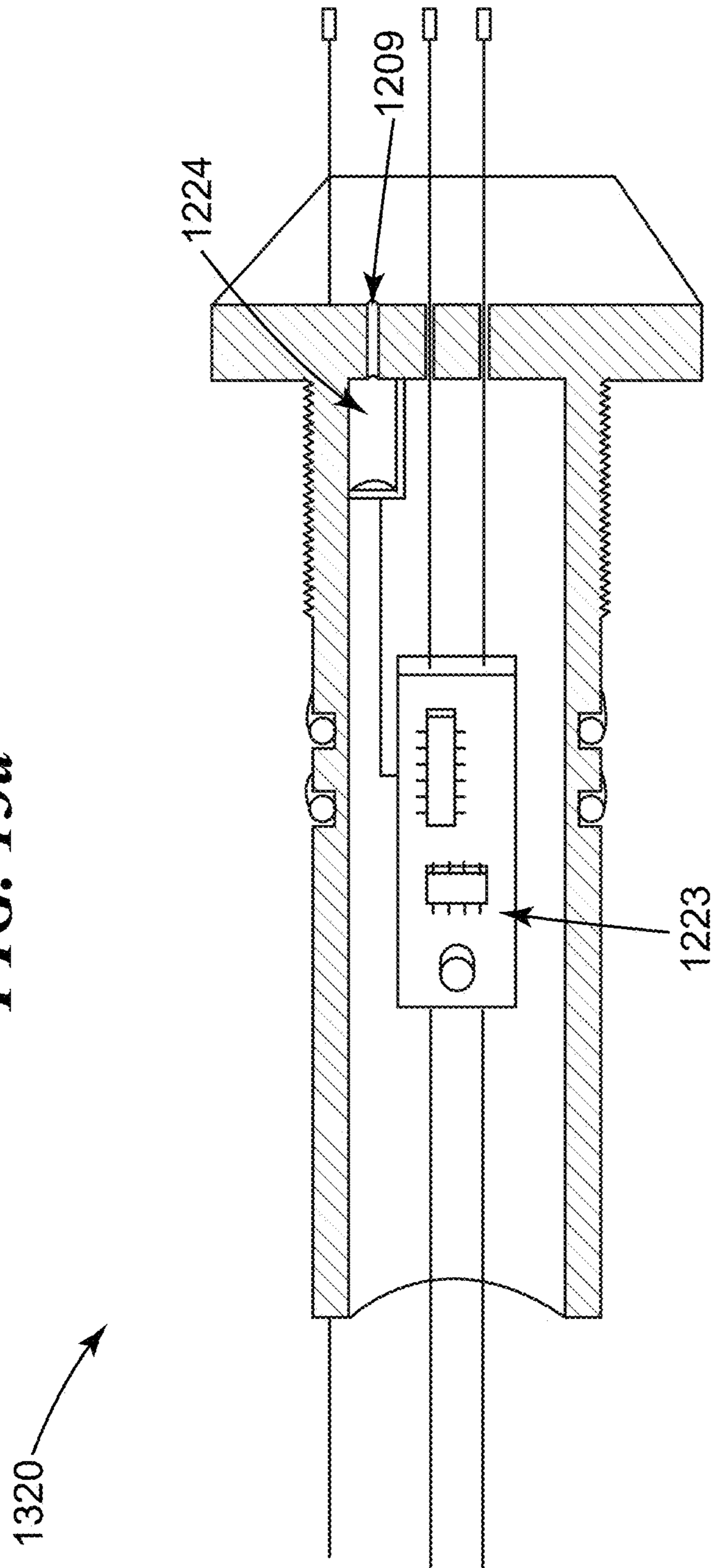


FIG. 14

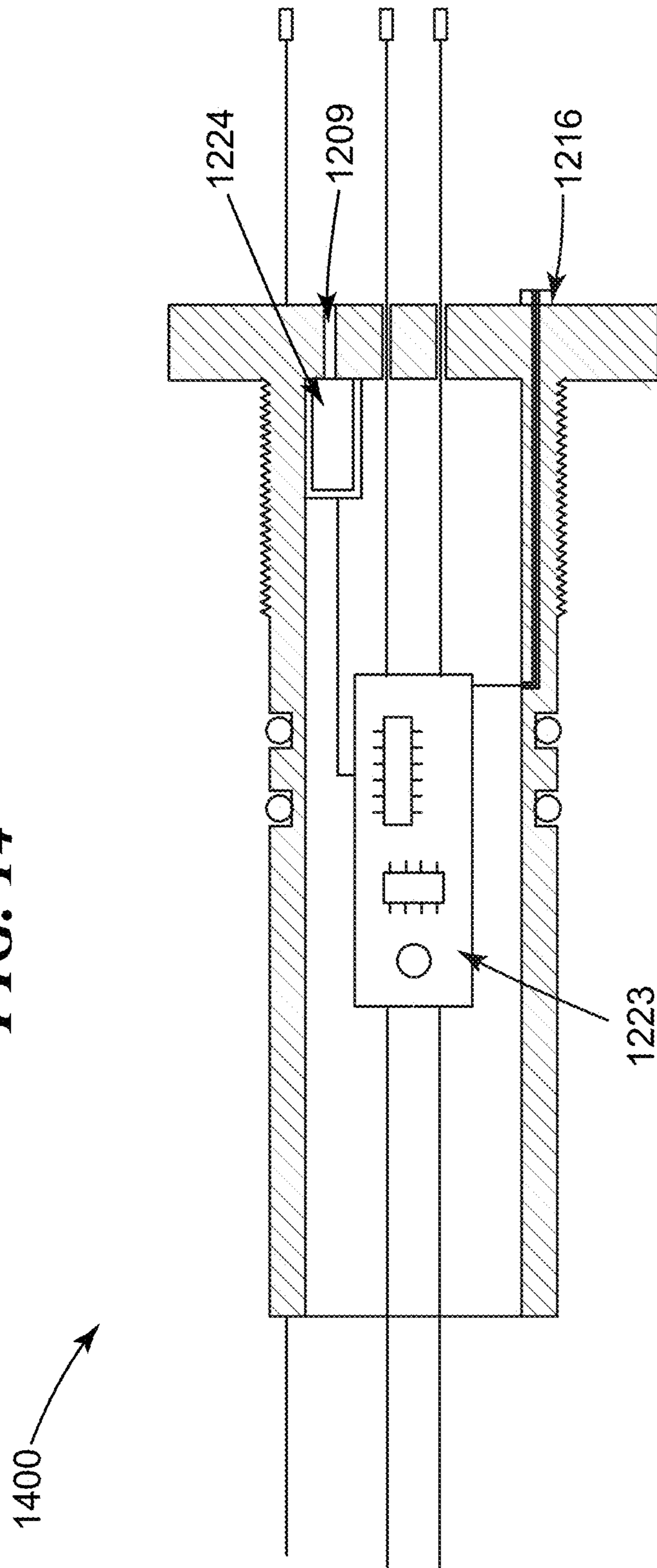
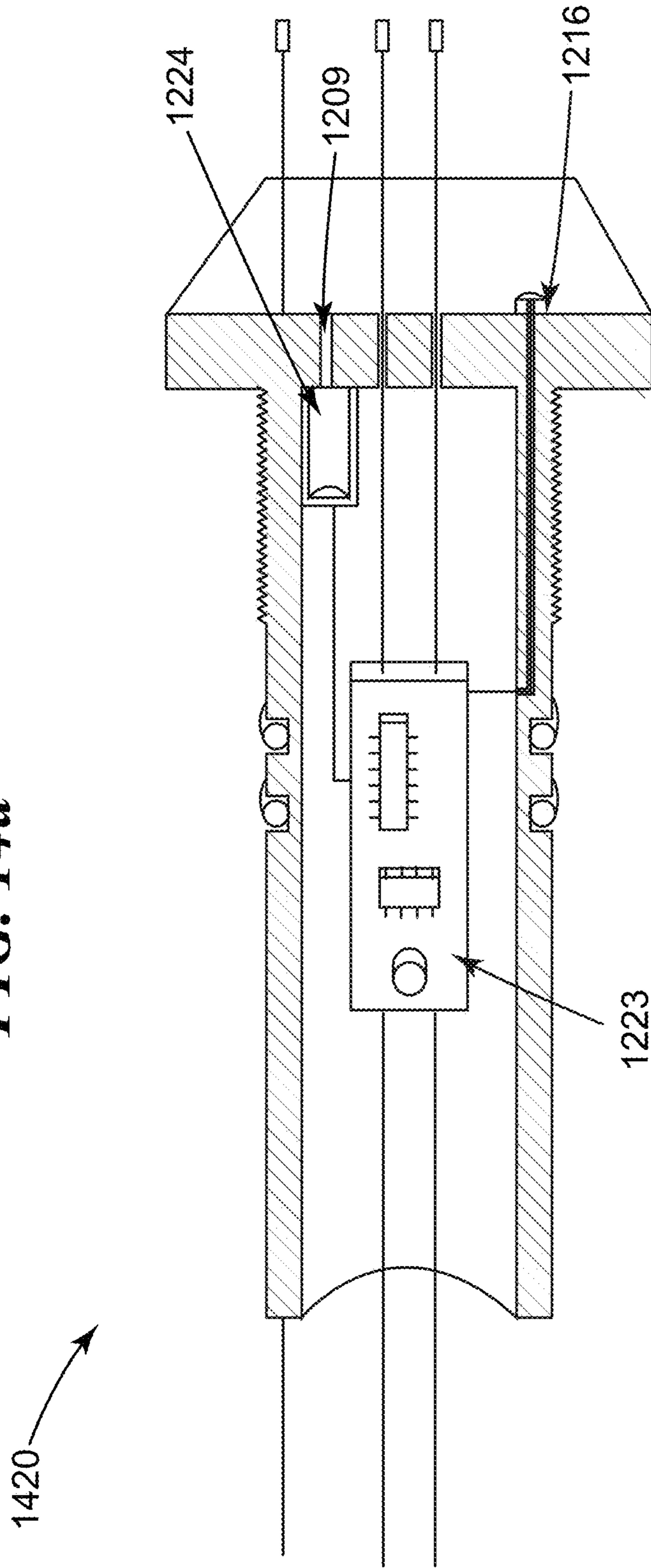


FIG. 14a



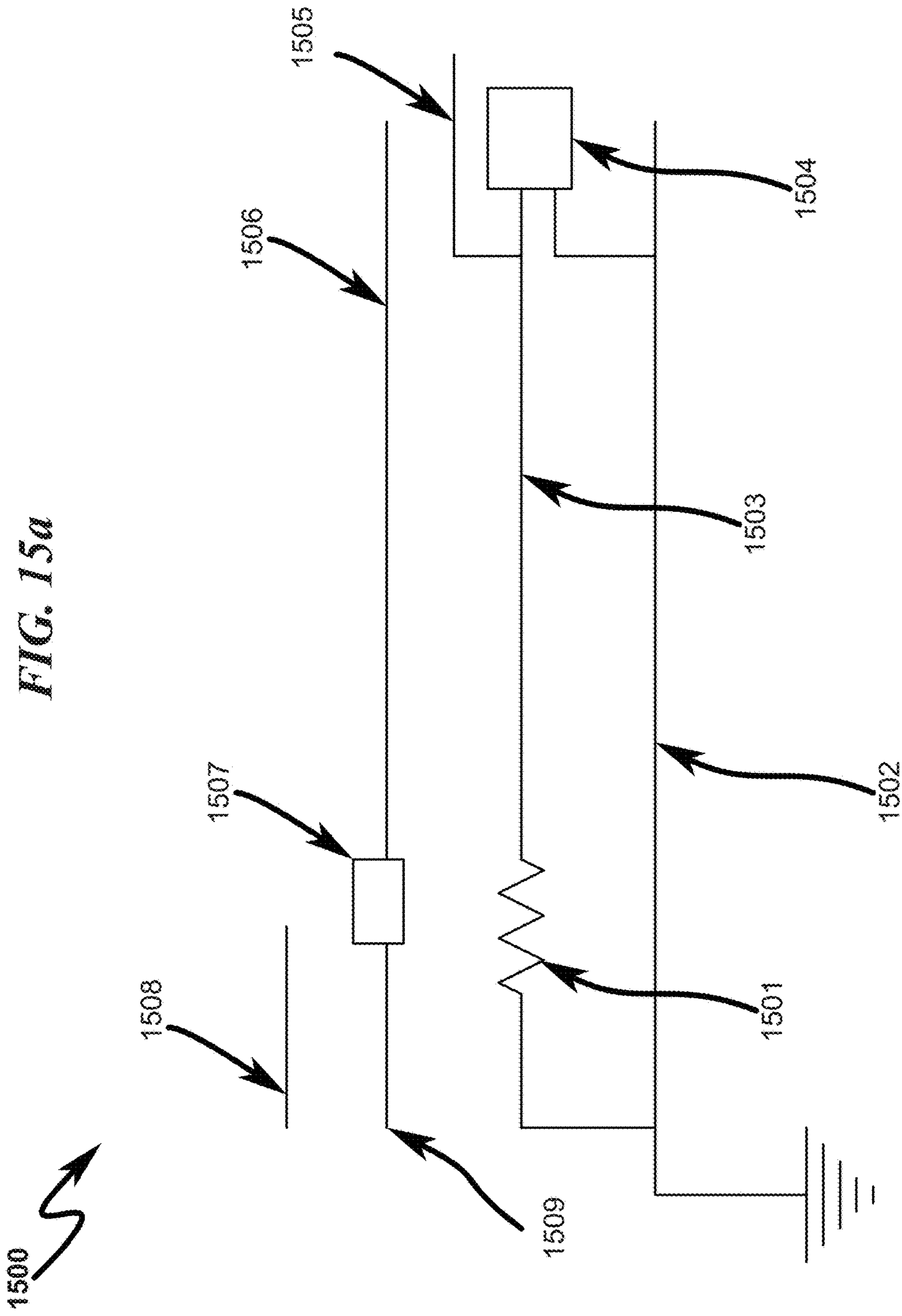


FIG. 16

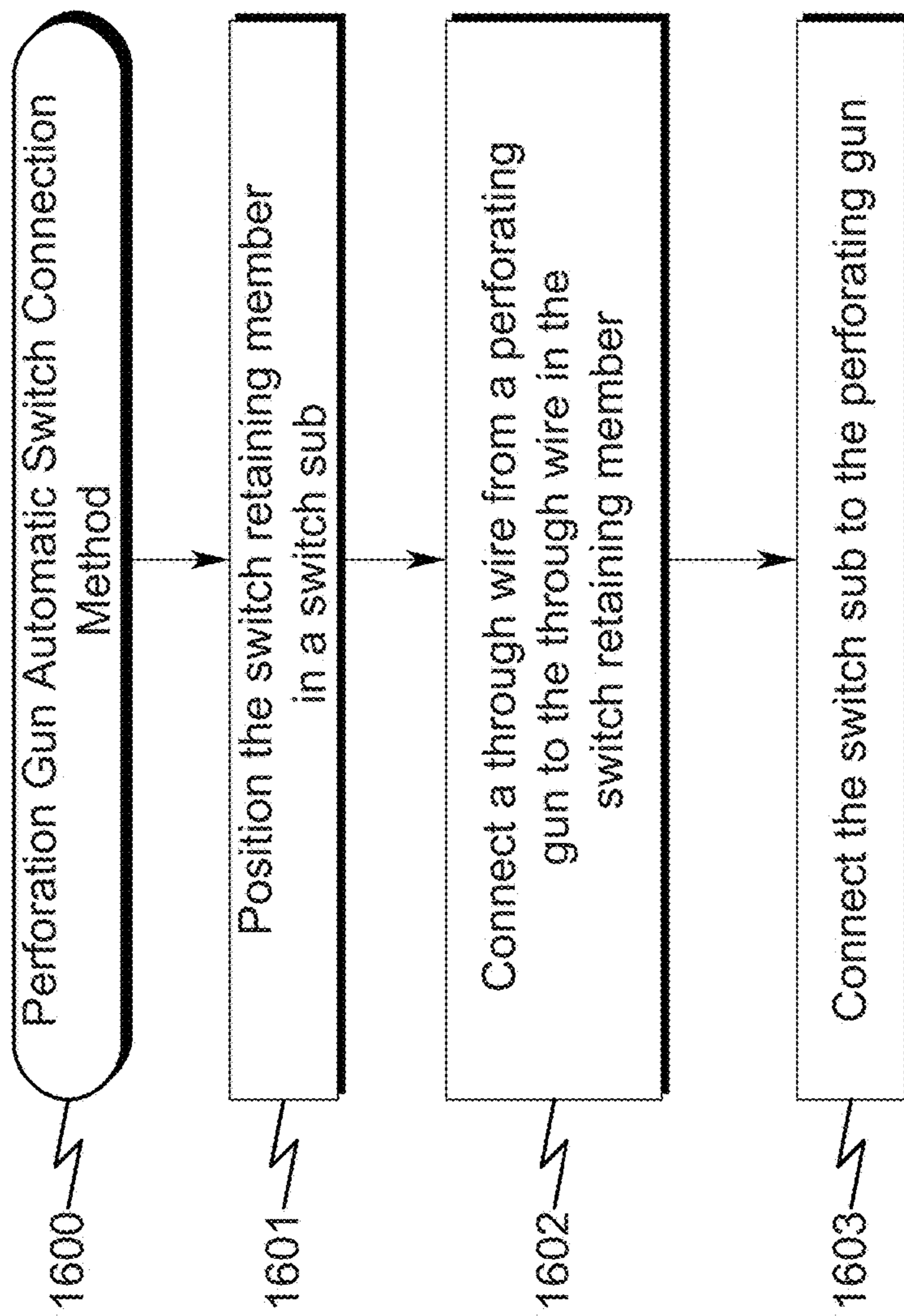
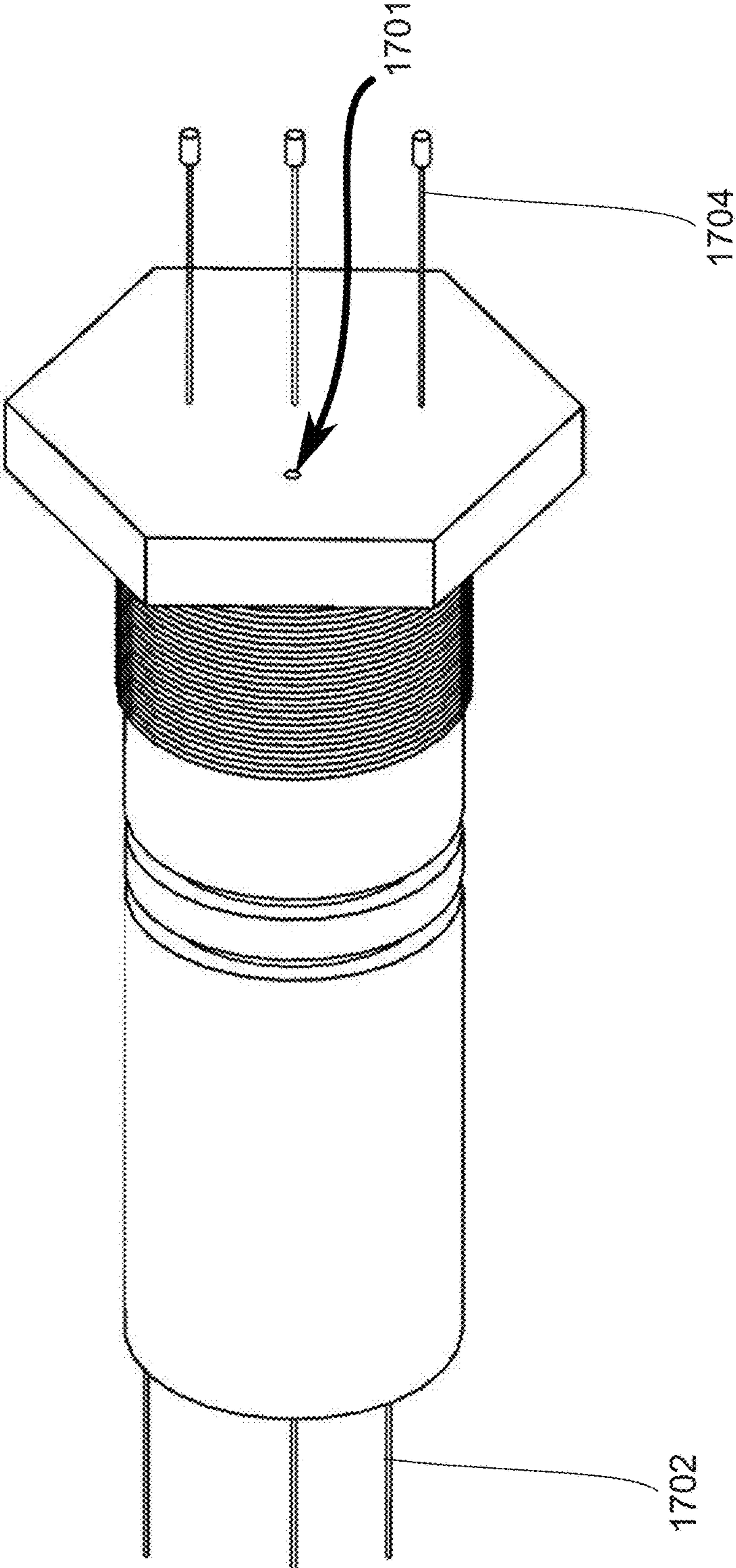
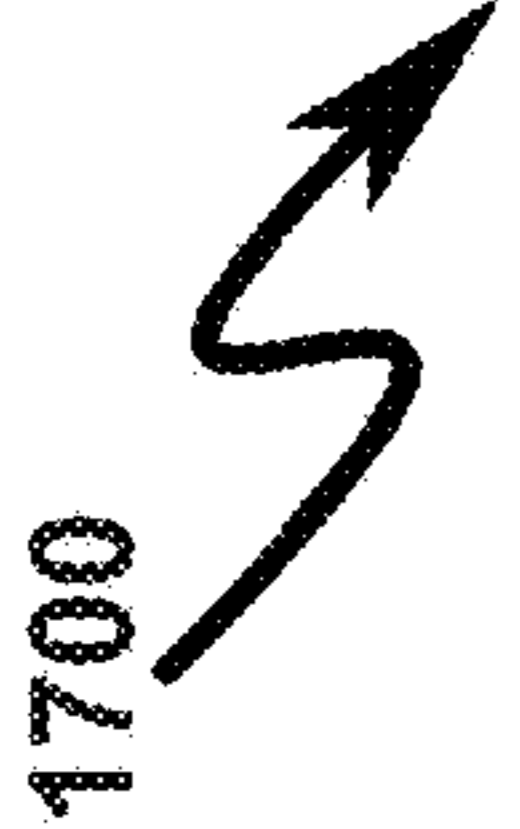
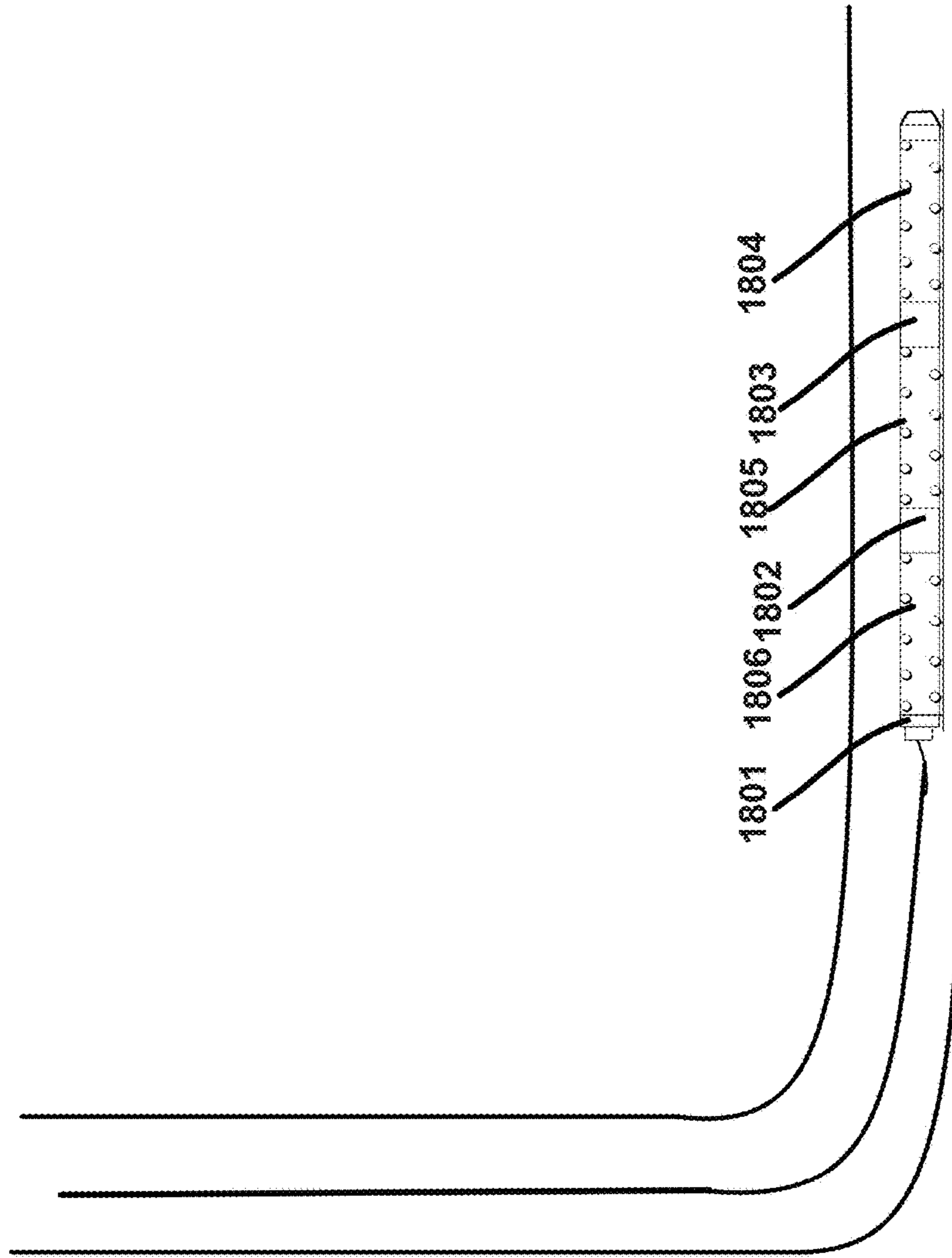


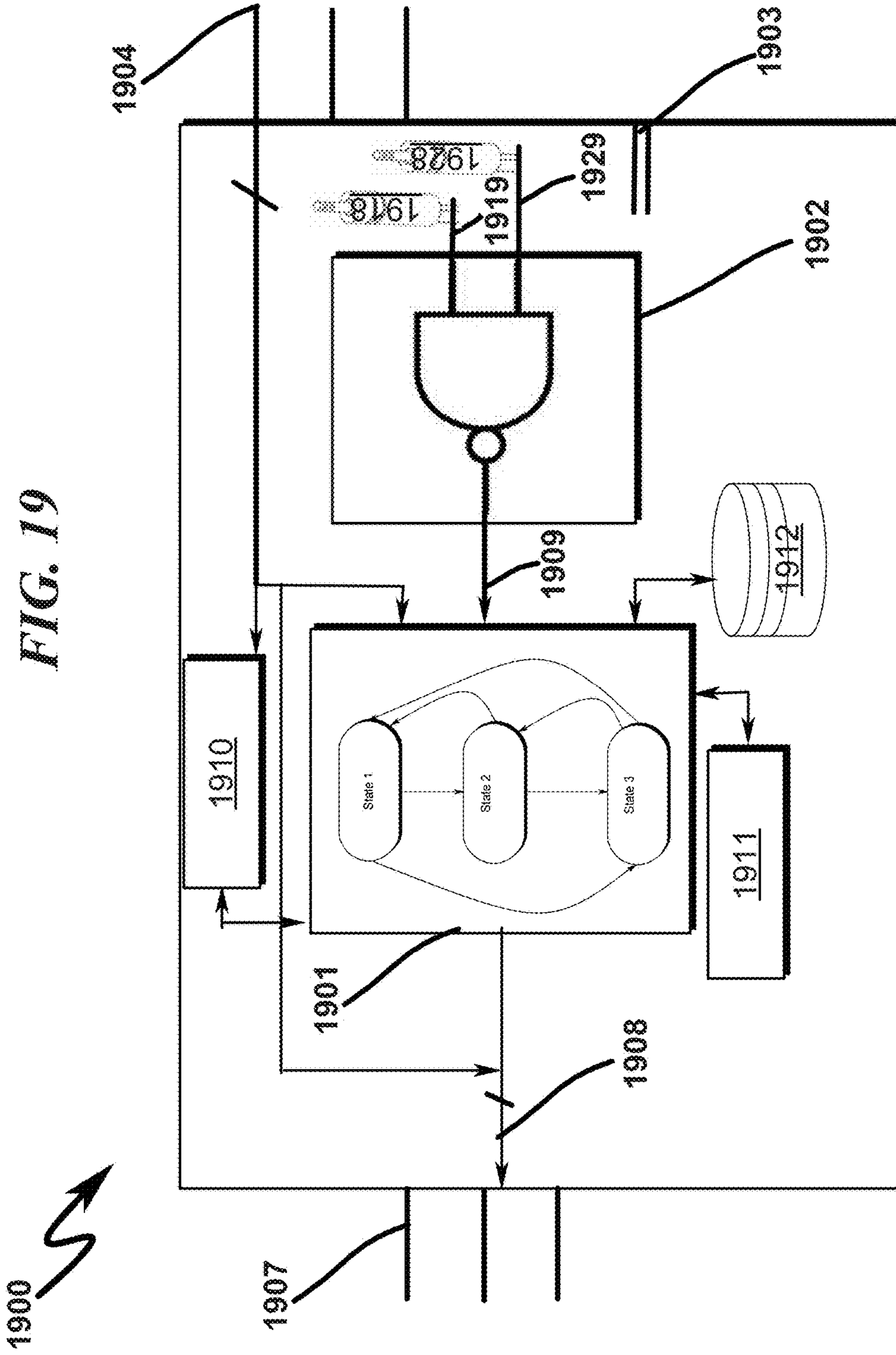
FIG. 17

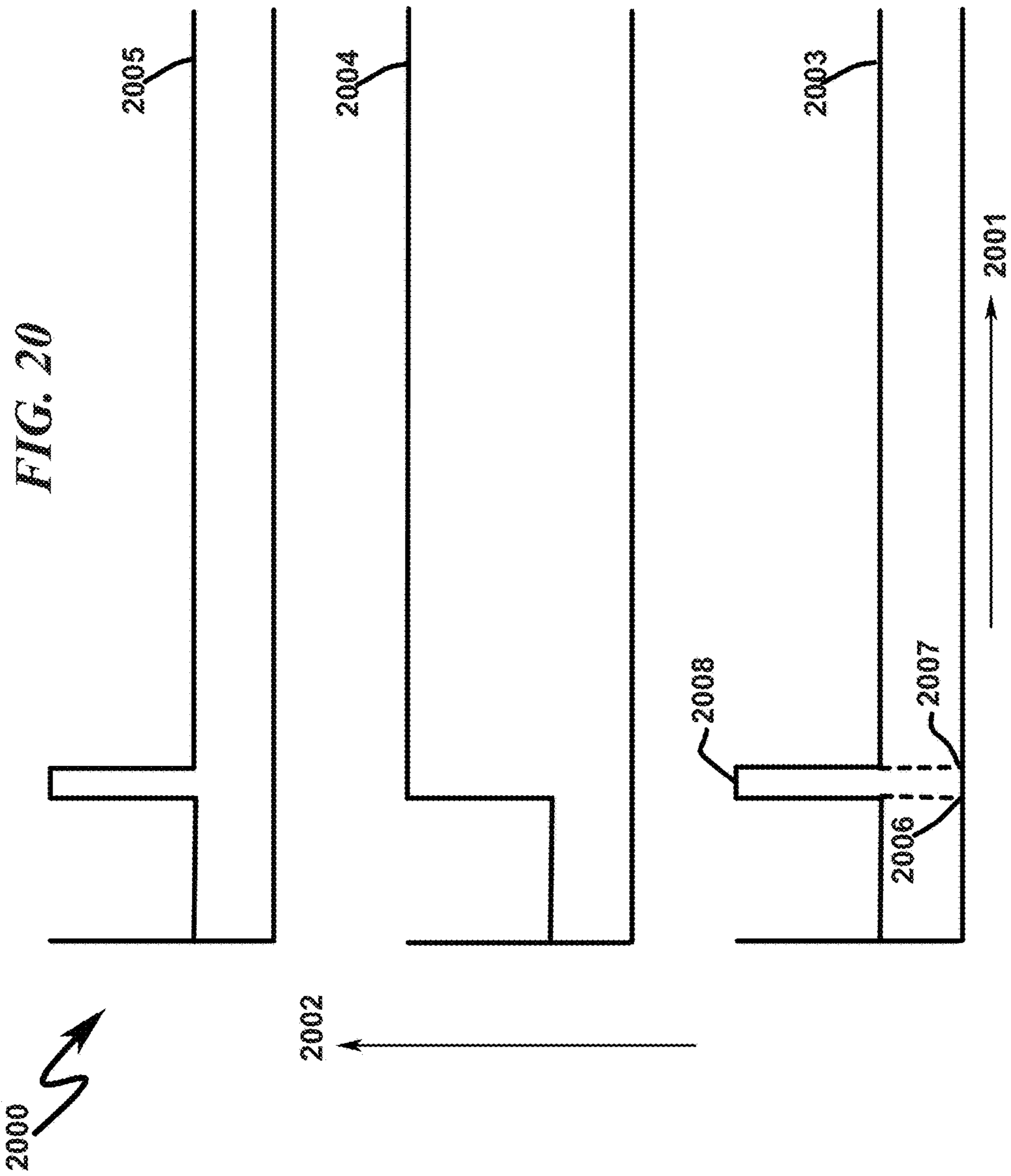


1800 ↗

FIG. 18

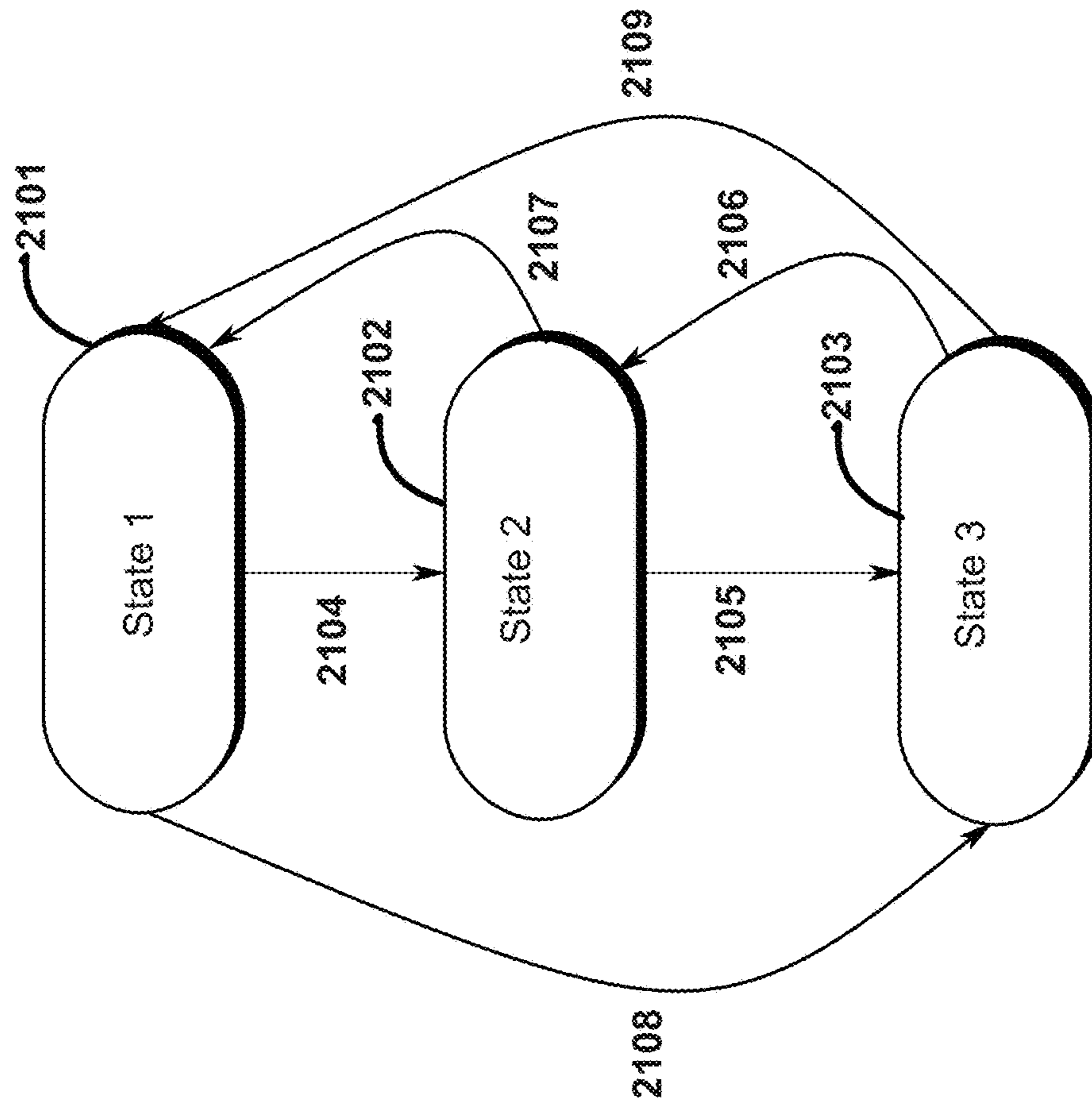


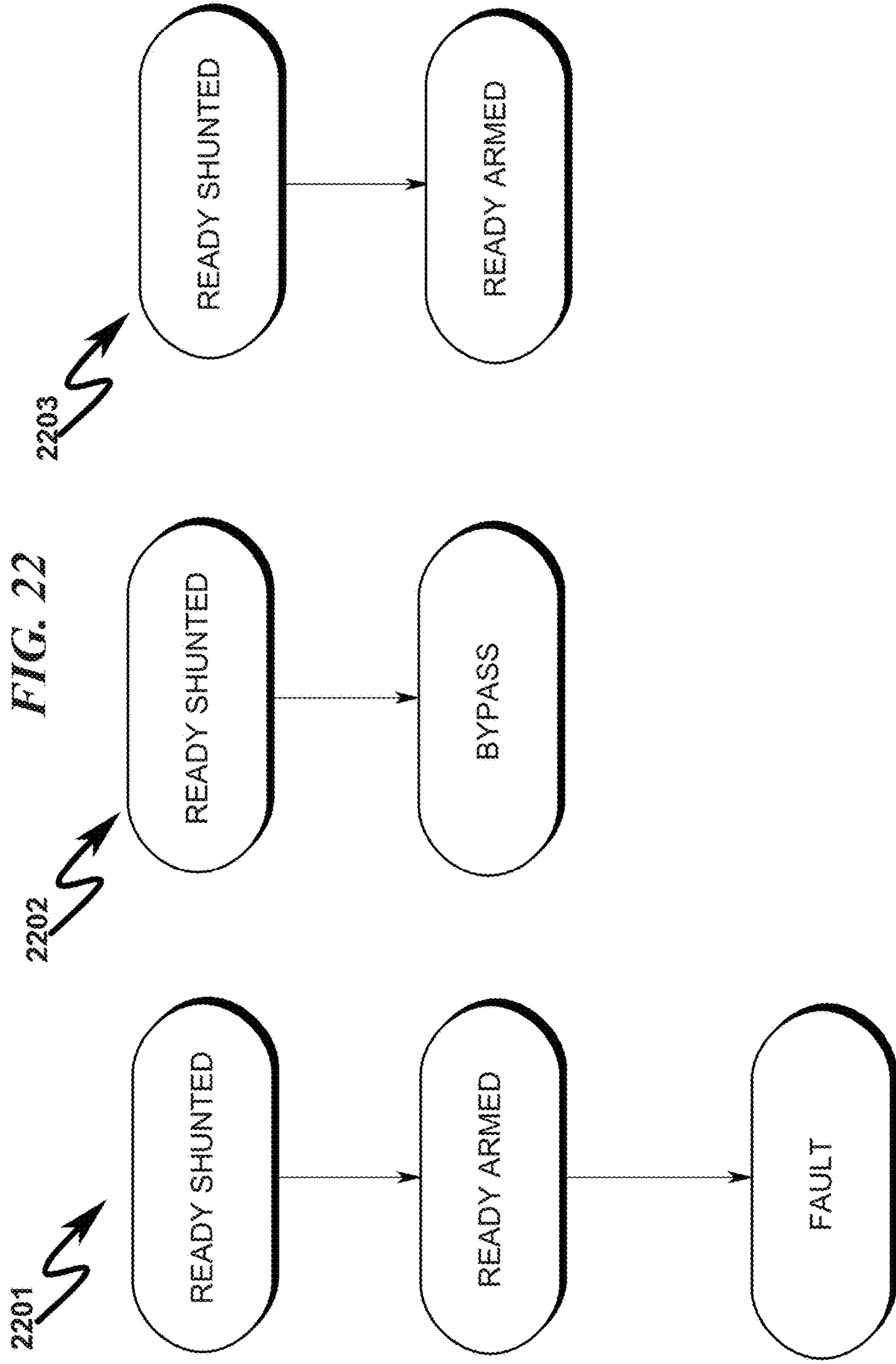




2100 ↗

FIG. 21





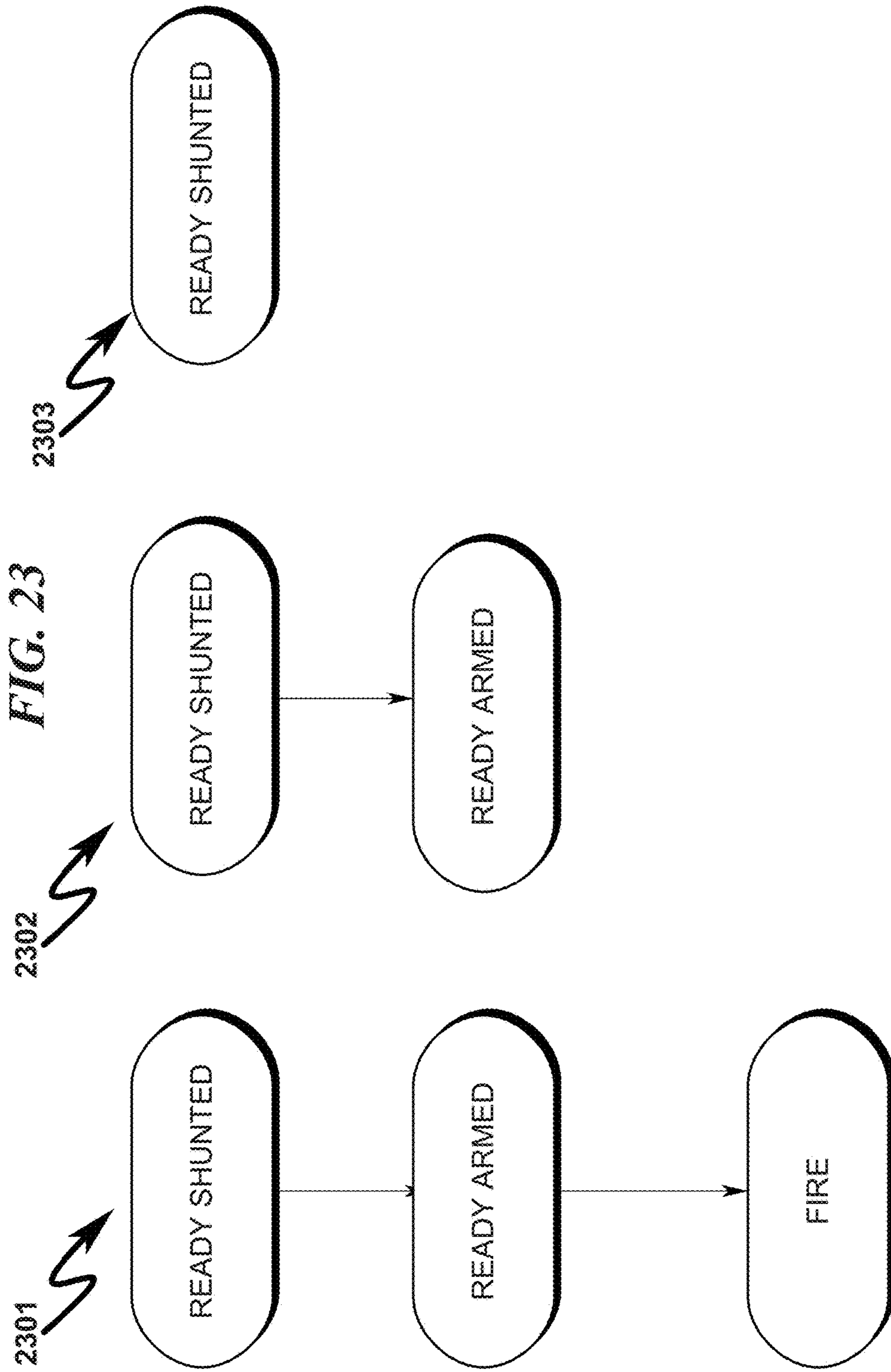


FIG. 24

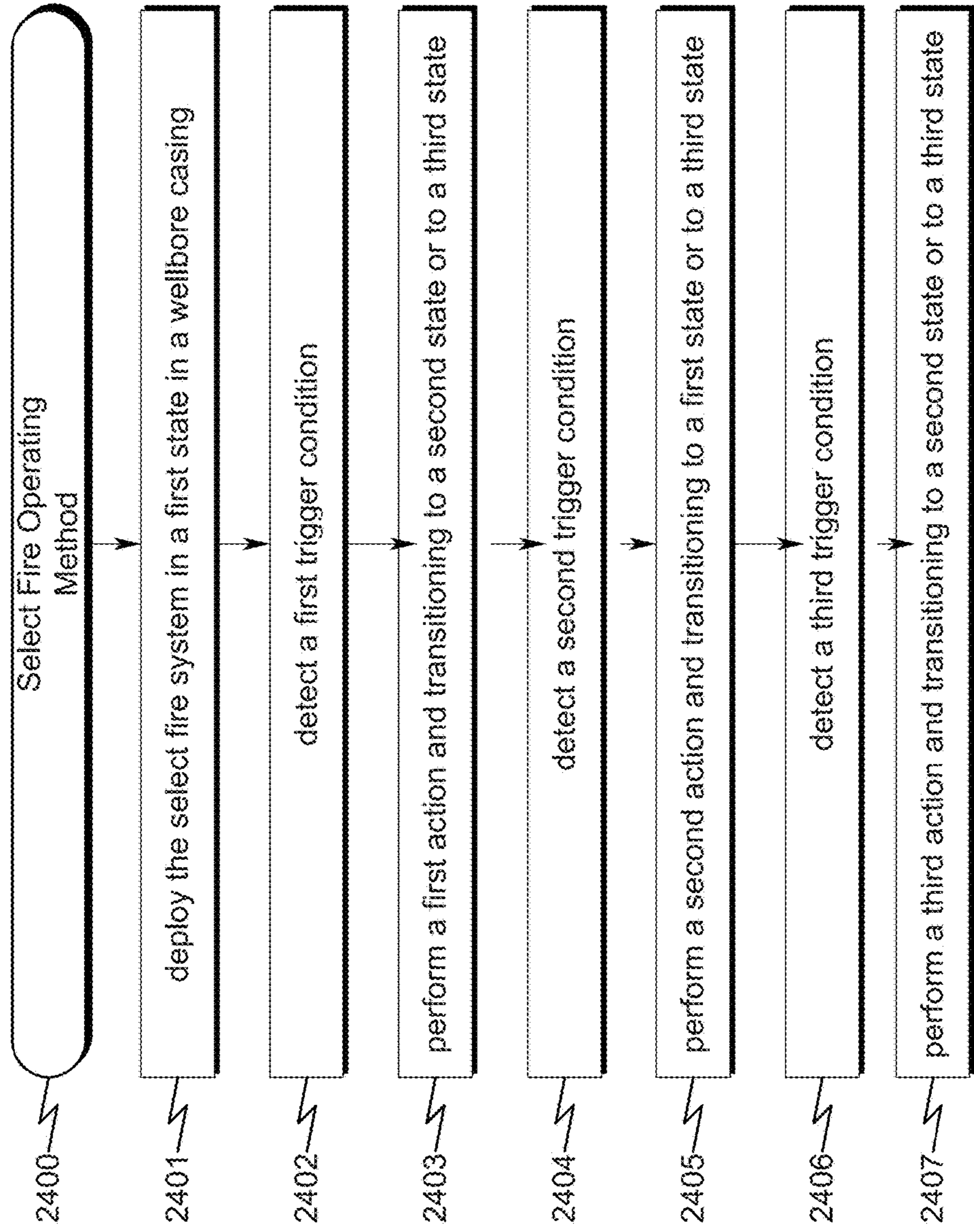
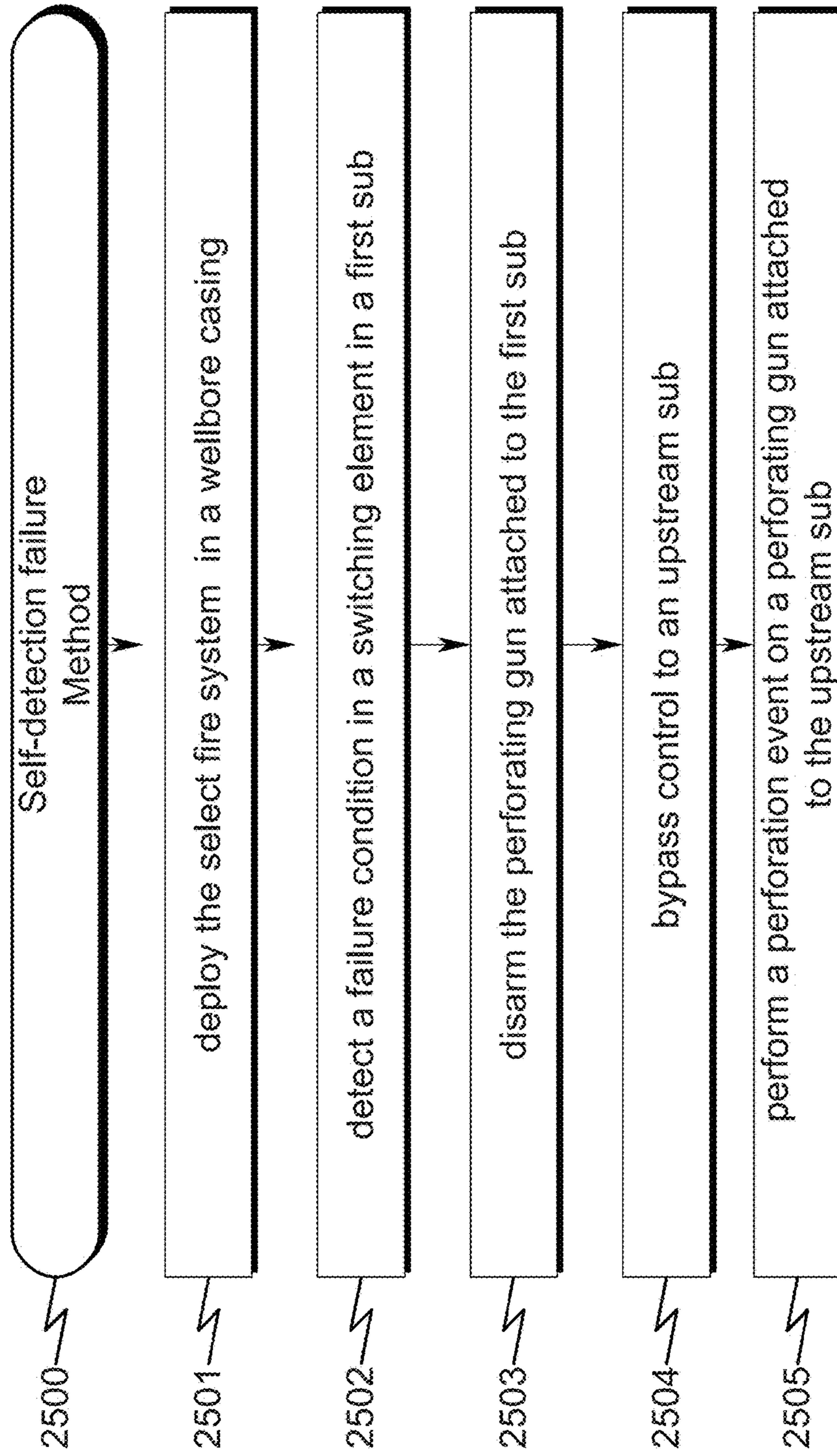


FIG. 25



SELECT FIRE SWITCH CONTROL SYSTEM AND METHOD

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. application Ser. No. 15/044,936, filed Feb. 16, 2016, which is a continuation of U.S. application Ser. No. 14/627,939, filed Feb. 20, 2015, the disclosures of which are fully incorporated herein by reference.

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STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable

REFERENCE TO A MICROFICHE APPENDIX

Not Applicable

FIELD OF THE INVENTION

The present invention generally relates to oil and gas extraction. Specifically, the invention attempts to control operations of switches and perforating guns in a gun string assembly.

PRIOR ART AND BACKGROUND OF THE INVENTION

Prior Art Background

The process of extracting oil and gas typically consists of operations that include preparation, drilling, completion, production, and abandonment.

The first step in completing a well is to create a connection between the final casing and the rock which is holding the oil and gas. There are various operations in which it may become necessary to isolate particular zones within the well. This is typically accomplished by temporarily plugging off the well casing at a given point or points with a plug.

A special tool, called a perforating gun, is lowered to the rock layer. This perforating gun is then fired, creating holes through the casing and the cement and into the targeted rock. These perforating holes connect the rock holding the oil and gas and the wellbore.

The perforating gun consists of four components, a conveyance for the shaped charge such as a hollow carrier (charge holder tube), the individual shaped charge, the detonator cord, and the detonator. A shaped charge perforating gun detonates almost instantaneously when the elec-

trical charge is sent from the perforating truck. In a detonation train there is a detonator/transfer, detonating cord, and energetic device (shaped charge/propellant). The shaped charges are sequentially detonated by the detonating cord from one end to other end of the perforating gun. The shaped charges perforate through scallops on the outside of the perforating gun so that the burr created is on the inside and not on the outside of the gun.

A gun string assembly is a system with cascaded guns that are connected to each other by tandems. Inside a tandem, a transfer happens between the detonating cords to detonate the next gun in the daisy chained gun string. Detonation can be initiated from the wireline used to deploy the gun string assembly electrically, through pressure activation, or electronic means.

In tandem systems there is a single detonating cord passing through the guns. There are no pressure barriers. However, in select fire systems (SFS) there is a pressure isolation/barrier switch between each gun. Each gun is selectively fired through its own detonation train. A detonator feeds off each switch. When the lower most perforating gun is perforated, pressure enters the inside of the gun. When the first gun is actuated, the second detonator gets armed when the pressure in the first gun switch moves into the next position actuating a firing pin to enable detonation in the next gun.

Pressure switches work by utilizing pressure shock waves generated by the detonation of perforating guns or by pressure in wellbore. The shock wave actuates an arming piston by pushing it to make contact with the proceeding detonator. A diode is connected to each switch such that all the guns do not initiate at once and restrict only one gun to initiate per firing sequence. Therefore positive (+) and negative (-) pressure switches are available to control firing selectivity. It is very important that they are correctly placed within the gun string such that each gun is selected and fired at the correct depth.

A gun string assembly (GSA) comprising a detonation train is positioned in a fracturing zone. The detonation train includes a detonator/transfer, detonating cord, and energetic device (shaped charge/propellant). Plural perforating guns are connected by a switch sub. The GSA is pumped into the wellbore casing with a wireline cable that has a conducting through wire. The switch sub has a switch that connects a through line to an input/fire line of a detonator, when enabled. The other input to the detonator is a ground line that is grounded to the sub body. The ground line may also be provided through a nut screwed to the switch sub. The through wire electrical connection from a perforating gun is connected to a switch inside the switch sub in the field of operations. The through wire is generally twisted to the center pin of the switch. A nut is used to hold the through wire and the switch in place. The through wire may lose electrical connection due to vibration and shock caused during deployment of the gun string assembly. However, the through wire connection to the switch center pin is not reliable and may not make a perfect electric connection. Therefore, there is a need for a pre-wired retaining member that has an integrated through wire. In addition, there is a need for a reliable ground connection to the switch instead of the conventionally used switch body. A ground for the detonator is connected to the surface of the switch body by scratching through the oxide. This method of ground connection is unreliable and may cause the detonator to misfire or not fire. Furthermore, electronic switches need a reliable

ground for the electronics circuits to function. Therefore, there is a need for a reliable ground connection in the switch and the detonator.

FIG. 1a (0100) and FIG. 1b (0120) illustrate a prior art switch nut that does not have a through wire integrated to the switch nut. A typical switch nut may have a main diameter of 0.875 inches with a 12 pitch threading (0.875-12 UN-2A). FIG. 1c (0140) and FIG. 1d (0160) illustrate a prior art pressure switch with a center pin (0161). A through wire (0162) and a fire/arm wire (0163) are shown as outputs from the pressure switch. A typical switch body may have a length of 2.0 inches, an inner diameter of 0.75 inches, and an outer diameter of 0.752 inches. The center pin length may be 0.56 inches and the switch nut may have a retaining head length of 0.19 inches.

Deficiencies in the Prior Art

The prior art as detailed above suffers from the following deficiencies:

Prior art systems do not provide for reliable connection mechanism needed to perforate hydrocarbon formations with a gun string assembly.

Prior art systems do not provide for integrating a through wire and a ground wire into the nut that holds the switch down in a sub.

Prior art systems do not provide for a connection mechanism with no manual connection steps.

Prior art systems do not provide for a reliable ground wire for the detonator in a perforating gun system for the detonation to function as desired.

Prior art systems do not provide for modular connections between the switch sub and a perforating gun.

Prior art system do not provide for a reliable through wire connection without twisting the through wire to the connecting pin.

Prior art systems do not provide for a single part solution with the switch nut and switch body integrated.

Prior art systems do not provide for electronic switches packaged in a pressure switch form factor.

While some of the prior art may teach some solutions to several of these problems, the core issue of reliably integrating a through wire to a center pin of a switch piston not been addressed by prior art.

OBJECTIVES OF THE INVENTION

Accordingly, the objectives of the present invention are (among others) to circumvent the deficiencies in the prior art and affect the following objectives:

Provide for reliable connection mechanism needed to perforate hydrocarbon formations with a gun string assembly.

Provide for integrating a through wire and a ground wire into the nut that holds the switch down in a sub.

Provide for a connection mechanism with no manual connection steps.

Provide for a reliable ground wire for the detonator in a perforating gun system for the detonation to function as desired.

Provide for modular connections between the switch sub and a perforating gun.

Provide for a reliable through wire connection without twisting the through wire to the connecting pin.

Provide for a single part solution with the switch nut and switch body integrated.

Provide for electronic switches packaged in a pressure switch form factor.

While these objectives should not be understood to limit the teachings of the present invention, in general these objectives are achieved in part or in whole by the disclosed invention that is discussed in the following sections. One skilled in the art will no doubt be able to select aspects of the present invention as disclosed to affect any combination of the objectives described above.

BRIEF SUMMARY OF THE INVENTION

System Overview

The present invention in various embodiments addresses one or more of the above objectives in the following manner. The system includes perforating guns and switch subs mechanically connected in a gun string assembly. Each of the switch subs further comprises a switching element, input links and output links. The switch subs and perforating guns communicate with each other through the input and output links. The switching elements keeps track of the state of the sub and switches states based on trigger conditions such as environment conditions, perforating gun conditions, or input conditions from surface.

Method Overview

The present invention system may be utilized in the context of an overall gas extraction method, wherein the select fire system described previously is controlled by a method having the following steps:

- (1) deploying the select fire system in a first state in a wellbore casing;
- (2) detecting a first trigger condition;
- (3) performing a first action and transitioning to a second state or to a third state;
- (4) detecting a second trigger condition;
- (5) performing a second action and transitioning to a third state or to the first state;
- (6) detecting a third trigger condition; and
- (7) performing a third action and transitioning to the first state or to the second state.

Integration of this and other preferred exemplary embodiment methods in conjunction with a variety of preferred exemplary embodiment systems are described herein in anticipation of the overall scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the advantages provided by the invention, reference should be made to the following detailed description together with the accompanying drawings wherein:

FIG. 1a illustrates a prior art front cross section view of a switch nut.

FIG. 1b illustrates a prior art perspective view of a switch nut.

FIG. 1c illustrates a prior art front cross section view of a pressure switch.

FIG. 1d illustrates a prior art perspective view of a pressure switch.

FIG. 2a illustrates an exemplary front cross section of a select fire switch first retaining member comprising a vent port, a through wire connected to a center pin, and a ground wire according to a preferred embodiment of the present invention.

FIG. 12 illustrates an exemplary front cross section view of a select fire switch form factor with a retaining member integrated to an electronic switch according to a preferred embodiment of the present invention.

FIG. 12a illustrates an exemplary perspective view of a select fire switch form factor with a retaining member integrated to an electronic switch according to a preferred embodiment of the present invention.

FIG. 13 illustrates an exemplary embodiment front cross section view of a select fire switch form factor with a retaining member having an external port integrated to an electronic switch according to a preferred embodiment of the present invention.

FIG. 13a illustrates an exemplary perspective view of a select fire switch form factor with a retaining member having an external port integrated to an electronic switch according to a preferred embodiment of the present invention.

FIG. 14 illustrates an exemplary front cross section view of a select fire switch form factor with a retaining member having an external port and sensor integrated to an electronic switch according to a preferred embodiment of the present invention.

FIG. 14a illustrates an exemplary perspective view of a select fire switch form factor with a retaining member having an external port and sensor integrated to an electronic switch according to a preferred embodiment of the present invention.

FIG. 15a illustrates an exemplary electrical diagram of a disarmed fusible solid state switch according to a preferred embodiment of the present invention.

FIG. 15b illustrates an exemplary electrical diagram of an armed fusible solid state switch according to a preferred embodiment of the present invention.

FIG. 16 illustrates a detailed flowchart select fire switch retaining member connection method according to a preferred exemplary invention embodiment.

FIG. 17 illustrates an exemplary switching element with an environmental sensing port and plurality of inputs and outputs according to a preferred embodiment.

FIG. 18 illustrates an exemplary system of perforating guns attached to exemplary switching element with environmental sensing ports according to a preferred embodiment.

FIG. 19 illustrates an exemplary switching element with an environmental sensing port and state machine components according to a preferred embodiment.

FIG. 20 illustrates an exemplary pressure vs time chart for the inputs and output to an exemplary logic element according to a preferred embodiment.

FIG. 21 illustrates an exemplary state machine diagram of exemplary switching elements in a perforating gun system according to a preferred embodiment.

FIG. 22 illustrates a fault detection example of states in a state machine diagram of exemplary switching elements in a perforating gun system according to a preferred embodiment.

FIG. 23 illustrates a proper functioning example of states in a state machine diagram of exemplary switching elements in a perforating gun system according to a preferred embodiment.

FIG. 24 illustrates a detailed flowchart select fire switch operating method according to a preferred exemplary invention embodiment.

FIG. 25 illustrates a detailed flowchart select fire switch self-detecting failure method according to a preferred exemplary invention embodiment.

DESCRIPTION OF THE PRESENTLY PREFERRED EXEMPLARY EMBODIMENTS

While this invention is susceptible of embodiment in many different forms, there is shown in the drawings and will herein be described in detailed preferred embodiment of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspect of the invention to the embodiment illustrated.

The numerous innovative teachings of the present application will be described with particular reference to the presently preferred embodiment, wherein these innovative teachings are advantageously applied to the particular problems of a select fire switch form factor system and method. However, it should be understood that this embodiment is only one example of the many advantageous uses of the innovative teachings herein. In general, statements made in the specification of the present application do not necessarily limit any of the various claimed inventions. Moreover, some statements may apply to some inventive features but not to others.

It should be noted that the term downstream is used to indicate a position that is closer to the toe end of the wellbore casing and the term upstream is used to indicate a position that is closer to the heel end of the wellbore casing. The term "fire wire" or "arming wire" is used to indicate an input that is electrically connected to a detonator. The term "through wire" is used to indicate a conducting electrical wire that is part of a wireline cable that is connected to a gun string assembly. The term "actuate" or "arming" is used to indicate the connection of a through wire to a fire wire that is connected to a detonator. The term "ground wire" is used to indicate an electrical ground. The term "firing a detonator or perforating gun" is used to indicate an event when an electrical signal is transmitted through a through wire to the fire wire of a detonator.

Preferred Embodiment Select Fire Switch First Retaining Member (0200-0240)

The present invention may be seen in more detail as generally illustrated in FIG. 2a (0200) and FIG. 2b (0220), wherein a select fire switch first retaining member with an integrated through wire link (0203) is shown. According to an exemplary embodiment, the first retaining member has a form factor that is acceptable by a switch sub. The first retaining member may be a nut with a threading member. The through wire (0203) may be part of the wireline that is used to pump down a gun string assembly. The through wire link (0203) is a conductor in a cable that is capable of handling high voltages transmitted from the surface of the oil rig. The through wire may be used to send a voltage signal to an armed detonator to initiate detonation in a detonation train in a perforating gun. The through wire link (0203) is connected between perforating guns through a switch sub. According to a preferred exemplary embodiment, the through wire is integrated to a switch retaining member such that the through wire is in operative electrical connection to a center pin (post) of a switch. As shown in FIG. 2a (0200), through wire link (0203) is electrically connected to a center pin (0206) that is in turn electrically connected to a switch piston (0208). According to a preferred exemplary embodiment, the through wire link (0203) may be connected to an external through wire member (0201). The switch first retaining member may comprise a retaining head (0204) attached to a threading member

(0207). The threading member (0207) may be used to screw the first retaining member to a switch sub to hold a switch in place. According to a preferred exemplary embodiment, a ground wire link (0205) may be integrated to the retaining member body so that a reliable ground is provided to the switch. According to another preferred exemplary embodiment, the ground wire link (0205) may be connected to an external ground wire member (0202). A vent port (0209) in the retaining member enables pressure communication between external actuating forces and the switch piston (0208). An insulating layer (0230) may isolate the electrically conducting layer and the switch ground layer. According to yet another preferred exemplary embodiment, when a perforating gun is detonated, the actuation forces act on the switch piston through the vent port, whereby the switch piston (0208) slides and arms a switch by connecting the through wire (0203) to an arming wire in a switch.

FIG. 2c (0230) generally illustrates a cross section of a first switch retaining member with multiple conductors integrated. A through wire (0203), ground wire (0205) and an arming wire (0221) is integrated to the switch retaining member. FIG. 2d (0240) generally illustrates a perspective view of a first switch retaining member with multiple conductors integrated.

As generally illustrated in FIG. 2e (0260), a first switch retaining member (0265) with multiple conductors (0266) is routed through a perforating gun (0267). The multi conductor may be output (0268) from the perforating gun for further connections to upstream/downstream switch subs. According to a preferred exemplary embodiment, the electrical multi conductor cable integrated to a retaining switch member may be connected and routed through a perforating gun.

Preferred Embodiment Select Fire Switch First
Retaining Member Integrated to a Switch (0250-
0280)

The present invention may be seen in more detail as generally illustrated in FIG. 3a (0300) and FIG. 3b (0320), wherein a select fire switch first retaining member is integrated with a switch into one integrated unit (unified switch). The first retaining member is integrated with a through wire link (0203) is shown. As shown in FIG. 3a (0300), through wire link (0203) is electrically connected to a through pin (0206) that is connected to a switch piston (0208). The through wire link (0203) may be connected to an external through wire member (0201). The switch first retaining member may comprise a retaining head (0204) attached to a threading member (0207). The threading member (0207) may be used to screw the first retaining member to a switch sub (0211) to hold a switch (0210) in place. As generally illustrated in FIG. 3c (0340) and FIG. 3d (0360), a ground wire link (0205) may be also be integrated to the retaining member body so that a reliable ground is provided to the switch. The ground wire link (0205) may be connected to an external ground wire member (0202). A vent port (0209) in the retaining member enables pressure communication between external actuating forces and the switch piston (0208). When a perforating gun is detonated, the actuation forces act on the switch piston through the vent port (0209), whereby the switch piston (0208) slides and arms the switch (0210) by connecting the through wire (0203) to an arming wire in the switch (0210).

According to a further preferred exemplary embodiment, the first retaining member may have a retaining head length of 0.19 inches. The length of the first retaining head may be

in the range of 0.1 inches to 0.5 inches. The first retaining head may be hexagonal or a square shape.

Preferred Embodiment Select Fire Switch Second
Retaining Member (0400-0620)

Preferred Exemplary Second Retaining Member
with Ground Wire and Through Wire (0400-0420)

The present invention may be seen in more detail as generally illustrated in FIG. 4a (0400) and FIG. 4b (0420), wherein a select fire switch second retaining member with an integrated through wire link (0403) is shown. According to an exemplary embodiment, the second retaining member has a form factor that is acceptable by a switch sub. The second retaining member may be a nut with a threading member. The through wire (0403) may be part of the wireline that is used to pump down a gun string assembly. According to a preferred exemplary embodiment, the through wire (0403) is integrated to a switch second retaining member such that the through wire (0403) is in operative electrical connection to a center pin (0406) of a switch. As shown in FIG. 4a (0420), through wire link (0403) is electrically connected to a center pin (0406) that is connected to a switch piston (0408). According to a preferred exemplary embodiment, the through wire link (0403) may be connected to an external through wire member (0401). The switch second retaining member may comprise a retaining head (0404) attached to a threading member (0407). The threading member (0407) may be used to screw the second switch retaining member to a switch sub to hold a switch in place. According to a preferred exemplary embodiment, a ground wire link (0405) may be integrated to the second switch retaining member body so that a reliable ground is provided to the switch. According to another preferred exemplary embodiment, the ground wire link (0405) may be connected to an external ground wire member (0402). A secondary piston (0409) in the retaining member enables pressure communication between external actuating forces and the primary piston (0408). The secondary piston (0409) may slide in an annulus/bore in the switch retaining member. The secondary piston (0409) is aligned to the primary piston in the switch. The secondary piston may be held by two grooves for O-rings. According to an exemplary embodiment, when pressure acts on the secondary piston (0409), the secondary piston (0409) slides and activates the primary piston such that said through wire link (0403) is in operative electrical connection to an arming wire in a detonator in the switch. When in operation, the secondary piston (0409) protects the primary piston (0408) and primary piston from being completely exposed to actuation forces and wellbore pressure. When actuation forces act on the secondary piston (0409), the secondary piston (0409) slides and acts on the entire area of the primary piston resulting to a more reliable connection of the through wire to the arming wire of a switch.

FIG. 4c (0440) generally illustrates a cross section of a first switch retaining member with multiple conductors integrated. A through wire (0403), ground wire (0405) and an arming wire (0421) is integrated to the switch retaining member. FIG. 4d (0460) generally illustrates a perspective view of a first switch retaining member with multiple conductors integrated.

According to a further preferred exemplary embodiment, the second retaining member may have a retaining head length of 0.19 inches. The length of the second retaining

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head may be in the range of 0.1 inches to 0.5 inches. The second retaining head may be hexagonal or a square shape. Preferred Exemplary Second Retaining Member with a Through Wire Integrated to a Switch (0500-0520)

As generally illustrated in FIG. 5 (0500), a front cross section view of a select fire switch second retaining member is integrated into one unit (unified switch) with a secondary piston (0509), a through wire (0503), and a pressure switch (0510). The integrated second retaining member may be positioned in a switch sub (0511). According to an exemplary embodiment, the second retaining member has a form factor that is acceptable by a switch sub (0511). The second retaining member may be a nut (0504) with a threading member (0507). A perspective view of the second retaining member integrated with the through wire and a switch is generally illustrated in FIG. 5a (0520).

Preferred Exemplary Second Retaining Member with a Through Wire and a Around Wire Integrated to a Switch (0600-0620)

As generally illustrated in FIG. 6 (0600), a front cross section view of a select fire switch second retaining member is integrated into one unit (unified switch) with a secondary piston (0509), a through wire link (0503), ground wire link (0505) and a pressure switch (0510). The integrated second retaining member may be positioned in a switch sub (0511). According to a preferred exemplary embodiment, the second retaining member has a form factor that is acceptable by a switch sub (0511). A perspective view of the second retaining member integrated with a switch is generally illustrated in FIG. 6a (0620).

Preferred Exemplary Embodiment First Retaining Member Integrated to a Pressure Switch with a Ground Wire Output (0700-0720)

As generally illustrated in cross section view FIG. 7 (0700) and perspective view FIG. 7a (0720), a select fire switch first retaining member is integrated with a through wire link (0703), a ground wire link (0705) and a pressure switch (0710). The integrated first retaining member may be positioned in a switch sub (0711). The switch may have a through wire output (0713), a fire/arm wire output (0717) and a ground wire output (0715). According to a preferred exemplary embodiment, the switch ground wire (0715) may be in operative electrical connection to the switch body. The switch ground wire (0715) may be connected to the next perforating gun. The switch ground wire (0715) may be connected to the next perforating gun and all the way to the ground on a cable head input. A reliable ground is needed for a switch to activate correctly and a detonator to fire as intended. According to a preferred exemplary embodiment, the switch ground wire provides a reliable electrical ground connection for further electrical connections. Conventional pressure switches do not provide a ground output wire from a switch. This ground wire may be connected to a detonator output so that the detonator functions as desired with the reliable ground input from the switch.

Preferred Exemplary Embodiment Second Retaining Member Integrated to a Pressure Switch with a Ground Wire Output (0800-0820)

As generally illustrated in cross section view FIG. 8 (0800) and perspective view FIG. 8a (0820), a select fire switch second retaining member is integrated with a through wire link (0803), a ground wire link (0805) and a pressure switch (0810). The integrated second retaining member may

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be positioned in a switch sub (0811). The switch may have a through wire output (0813), a fire/arm wire output (0817) and a ground wire output (0815). According to a preferred exemplary embodiment, the switch ground wire (0815) may be in operative electrical connection to the switch body. The switch ground wire (0815) may be connected to the next upstream perforating gun. The switch ground wire (0815) may be connected to the next upstream perforating gun and all the way to the ground on a cable head input. A reliable ground is needed for a switch to activate correctly and a detonator to fire as intended. According to a preferred exemplary embodiment, the switch ground wire provides a reliable electrical ground connection for further electrical connections. Conventional pressure switches do not provide a ground output wire from a switch. The ground output wire may be connected to a detonator output so that the detonator functions as desired with the reliable ground input from the switch.

According to a preferred exemplary embodiment, the ground wire output may be in electrical connection to a ground body of a conventional pressure switch that is connected to switch nut used in the art. As generally illustrated in front view of FIG. 8b (0840) and perspective view of FIG. 8c (0860), the ground wire (0811) is integrated to the body of the pressure switch. The other outputs from the switch are a through wire (0812) and a fire/arming wire (0813). Another exemplary cross section of the pressure switch with a ground wire integrated to the switch body is generally illustrated in FIG. 8d (0880). A perspective is illustrated in FIG. 8e (0890).

Preferred Exemplary Embodiment Switch with Plural Inputs and Plural Outputs (0900-1020)

As generally illustrated in FIG. 9 (0900), FIG. 9a (0920), FIG. 10 (1000) and FIG. 10a (1020), an integrated switch (integrated unit) with a plurality of inputs (0901, 0902, 0903) and plurality of outputs (0911, 0912, 0913) is shown. The integrated switch may comprise an integrated retaining member with a switch body that encapsulates an activating switch member. According to a preferred exemplary embodiment, the switch activating member may be a pressure switch integrated to the retaining member. According to another preferred exemplary embodiment, the switch activating member may be an electronic switch integrated to the retaining member. According to a further preferred exemplary embodiment, the switch activating member may be a mechanical switch integrated to the retaining member. According to yet another preferred exemplary embodiment, the switch activating member may be a solid state switch integrated to the retaining member. The switch body (0906) may be in a cylindrical encapsulated body format with the retaining member integrated on one end. The retaining member may comprise a retaining head (0904) attached to a threading member (0905). The retaining head may be hexagonal or a square shape. The threading member (0905) may be utilized to screw/attach the integrated switch directly to a switch sub. The form factor of the integrated switch is such that it can be inserted/positioned/screwed into a conventional switch sub without the need for a separate retaining member to hold down the switch. The switch body may have a form factor of a conventional pressure switch currently used in the art.

According to a preferred exemplary embodiment, the threading member may have a main diameter of 0.875 inches with a 12 pitch threading. The threading member may have a main diameter within a range of 0.25 inches to 2.0

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inches. According to another preferred exemplary embodiment, the switch body may have a length of 2.0 inches, an outer diameter of 0.75 inches. The length of the switch body may be in the range of 1.5-4 inches. The outer diameter of the switch body may be in the range of 0.25-2.0 inches. According to another preferred exemplary embodiment, the switch body has length equal to the length of the switch sub. According to yet another preferred exemplary embodiment, the center pin attached to the switch body may be 0.56 inches. The length of the center pin may be in the range of 0.4 inches to 0.8 inches. According to a further preferred exemplary embodiment, the retaining member may have a retaining head length of 0.19 inches. The length of the retaining head may be in the range of 0.1 inches to 0.5 inches.

According to a preferred exemplary embodiment, the switch body may be an electronic switch shaped in cylindrical form factor. According to another preferred exemplary embodiment, the switch body may be a solid state switch shaped in cylindrical form factor. According to a further preferred exemplary embodiment, the switch body may be a mechanical switch shaped in cylindrical form factor. The plural inputs (0901, 0902, 0903) may be a ground wire, a through wire and general purpose electric or electronic signals. For example, one of the plural inputs may be a communication signal to arm the switch (0906). In another example, one of the plural inputs may be a communication signal to bypass a switch. In yet another example, one of the plural inputs may be a communication signal to enable fault/error detection the switch. Similarly, the plural outputs (0911, 0912, 0913) may be a ground wire, a through wire and general purpose electric or electronic signals. For example, one of the plural outputs may be a communication signal to indicate the status of the switch activating member. In another example, one of the plural outputs may be a communication signal to enable the next upstream switch. In yet another example, one of the plural outputs may be a communication signal to enable fire the next upstream or downstream perforating gun.

As illustrated in FIG. 10a (1020), the integrated switch may be incorporated with an external port ("switch port") (0907). According to a preferred exemplary embodiment, the external port is configured to detect pressure conditions in the switch. The external port may be configured on both sides of the retaining member in the integrated switch. According to another preferred exemplary embodiment, the external port is configured to monitor temperature conditions. According to yet another preferred exemplary embodiment, the external port (0907) is configured to sense the presence of hydrocarbons, gas, water, brine, or other liquids. The external port may communicate the quality and chemical composition of the hydrocarbon in the wellbore through one of the plural outputs. Depending on the results of the hydrocarbon, an operator may then make a decision to activate or skip the next perforating gun and communicate the decision to the switch sub through one of the plural inputs. The external port may also detect conditions such as hang fire. Hang fire detection may substantially improve the safety when the gun string assembly is pulled out of the wellbore casing. According to a further preferred exemplary embodiment, the external port is configured to sense any environmental variables. According to yet another preferred exemplary embodiment, the external port detects pressure pulses to arm or disarm a switch. For example, a switch may detect 5 pressure pulses to arm the current switch. Similarly, a 4 pulse signal may indicate to bypass the current switch and a 3 pulse signal may indicate to fire the current switch.

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The pressure pulses are generated through pumping the pressure up or down from the surface of the wellbore. The plural outputs may be configured to communicate the output of the external port to surface and react accordingly by sending a signal to the integrated switch through one of the plural inputs. For example, if the external port (0907) detects excess temperature in the switch, a signal may be sent through an output (0911) to a monitoring system at the surface or to an operator. The monitoring system may react and send a communication signal to disarm the switch through an input (0901) signal. It should be noted that the plural inputs and outputs may be utilized as a feedback mechanism to detect faults, react to faults, and arm/disarm switches. A real time monitor may be established with the feedback mechanism built into the input and output signals. According to a most preferred embodiment, a detonator is integrated to an upstream end of the integrated switch. According to another most preferred embodiment, a detonator is integrated to a downstream end of the integrated switch. The detonator may be configured to be electrically connected to the through wire/arming wire and the ground wire of the inputs or to the through wire/arming wire and the ground wire of the outputs.

Preferred Exemplary Integrated First Retaining Member Switch (1100-1120)

Similar to the integrated switch of FIG. 10 (1000), an integrated first retaining member switch is generally illustrated in front cross section FIG. 11 (1100) and perspective view in FIG. 11a (1120). An integrated first retaining member switch (integrated first unit) integrates a first retaining member as aforementioned in FIG. 2 (0200) with a plurality of inputs (1102, 1103), plurality of outputs (1111, 1112, 1113) and a switch body (1106). The switch body (1106) may be in a cylindrical encapsulated body format with the retaining member integrated on one end. The retaining member may comprise a retaining head (1104) attached to a threading member (1105). The threading member (1105) may be utilized to screw/attach the integrated switch directly to a switch sub. The form factor of the integrated first unit is such that it can be inserted/positioned/screwed into a conventional switch sub without the need for a separate retaining member to hold down the switch. The switch body may be a conventional pressure switch currently used in the art. A vent port (1109) in the first retaining member may be used to actuate a piston in the switch. The integration of the first retaining member and a switch along with plural inputs and plural outputs enables feasibility, reliability program-mability and usability in the overall scheme of switch sub to perforating gun connections. A perspective view of a first retaining member integrated to a switch and positioned in a switch sub is generally illustrated in FIG. 11a (1140, 1120).

Preferred Exemplary Integrated Electronic Switch (1200-1420)

Similar to the integrated switch of FIG. 10 (1000), as generally illustrated in FIG. 12 (1200), FIG. 12a (1220), FIG. 13 (1300), FIG. 13a (1320), FIG. 14 (1400) and FIG. 14a (1420), an integrated electronic switch (integrated electronic unit) with a plurality of inputs (1201, 1202, 1203) and plurality of outputs (1211, 1212, 1213) is shown. The integrated electronic switch may comprise an integrated retaining member with an electronic switch (1223) encapsulated in a cylindrical switch body (activating switch member). The electronic switch receives electrical power

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from a through wire in one of the plural inputs or through an on board battery/power source. The switch body (1206) may be in a cylindrical encapsulated body format with the retaining member integrated on one end. The retaining member may comprise a retaining head (1204) attached to a threading member (1205). The threading member (1205) may be utilized to screw/attach the integrated switch directly to a switch sub. The form factor of the integrated switch is such that it can be inserted/positioned/screwed into a conventional switch sub without the need for a separate retaining member to hold down the switch. The integrated electronic switch may be used in conventional switch subs and connected to perforating guns without the need for manual connections to the switch. FIG. 14 (1400) illustrates a vent port (1209) integrated to the retaining end of the integrated switch. FIG. 14 (1400) also illustrates an external sensor (1216) integrated to the retaining end of the integrated switch. The electronic switch (1223) may be pressure isolated with an isolation chamber (1224). The external sensor may be used to detect environmental conditions such as temperature, pressure, and/or chemical composition of gases and/or liquids in the wellbore. The plural outputs may be configured to communicate the output of the external port to an operator/monitor at the surface which may react accordingly by sending a signal to the integrated electronic switch through one of the plural inputs.

Preferred Exemplary Integrated Electronic Switch
(1500-1520)

Similar to the integrated switch of FIG. 10 (1000), as generally illustrated in FIG. 15a (1500) an integrated solid state switch (integrated solid state unit) electrical diagram in a disarmed state is shown. The integrated solid state switch may comprise an integrated retaining member with a solid state switch encapsulated in a cylindrical switch body (activating switch member). The switch body may be in a cylindrical encapsulated body format with the retaining member integrated on one end. The retaining member may comprise a retaining head attached to a threading member. The threading member may be utilized to screw/attach the integrated switch directly to a switch sub. The form factor of the integrated switch is such that it can be inserted/positioned/screwed into a conventional switch sub without the need for a separate retaining member to hold down the switch. An input through wire (1506) is electrically connected to an output through wire (1509) through a connecting member (1507). A detonator (1504) is connected to an input fire wire (1505) and an electrical ground (1502). The fire wire (1505) may also be electrically connected in series or parallel to a fusible resistor (1501). An output fire wire (1508) is initially floating and not connected electrically. When the input fire wire (1505) is actuated/armed, then the fusible resistor (1501) may heat and enable connecting member to disconnect electrically from through wire (1506) and connect output through wire (1509) to output fire wire (1508) as shown in FIG. 15b (1520). The connecting member (1507) may be a eutectic, a carbon fuse, or a mechanical slider. According to a preferred exemplary embodiment, when a detonation event happens, an input through wire (1506) is disconnected and an output through wire is connected to an output fire wire with a fusible link between each other.

Preferred Exemplary Wellbore Perforating Gun
Flowchart Embodiment (1600)

As generally seen in the flow chart of FIG. 16 (1600), a preferred exemplary select fire switch retaining member connection method may be generally described in terms of the following steps:

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- (1) Positioning the switch retaining member in a switch sub (1601);
- (2) Connecting a through wire from a perforating gun to the through wire in the switch retaining member (1602); and
- (3) Connecting the switch sub to the perforating gun (1603).

FIG. 17 generally illustrates a switching element or integrated switch (1700) integrated with a plurality of input links (1701) and a plurality of output links (1702). The switching element may be similar to the integrated switch of FIG. 10a (1020). The switching element with the plurality of input links and a plurality of output links may be positioned in a switch sub (not shown). The switch sub may be mechanically connected to perforating guns as illustrated in FIG. 18 (1800). As generally illustrated in FIG. 18 (1800), switch sub (1803) is connected to gun (1804) on a downstream end and to gun (1805) on an upstream end. Similarly, switch sub (1802) is connected to gun (1805) on a downstream end and to gun (1806) on an upstream end. The gun (1806) may be attached to another switch sub (1801) on the gun's (1806) upstream end. A gun string assembly may be formed with the switch subs and guns as illustrated in FIG. 18 (1800). A switching element may be positioned in each of the switch subs. The switching element may further comprise an environmental sensing port (1704) that may sense or detect pressure conditions in the switch. The sensing port may be configured on either end of the switching sub. The switching element may sense well conditions, perforating gun conditions, and input conditions from surface. For example, the switching element in sub (1803) may detect the pressure condition of gun (1804). A pressure switch in the switching element may react according to the detected pressure. When the gun (1804) fires, wellbore fluids may flood the gun and the sensing port (1704) may detect a wellbore pressure or other environmental conditions. According to another preferred exemplary embodiment, the sensing port may monitor temperature conditions. For example, the sensing port may sense over temperature due to explosive degradation. According to yet another preferred exemplary embodiment, the sensing port (1704) senses the presence of hydrocarbons, gas, water, brine, or other liquids. The sensing port may communicate the quality and chemical composition of the hydrocarbon in the wellbore through one of the plural outputs (1702). Depending on the results of the hydrocarbon, an operator may then make a decision to activate or skip the next perforating gun and communicate the decision to the switch sub through one of the plural inputs (1701). The sensing port may also detect conditions such as hang fire and communicate the condition to switch subs upstream or to surface. For example, if a hang fire condition is detected in gun (1805), switch (1803) may communicate to switch (1802) and disarm or skip gun (1805). Alternatively, switch (1803) may communicate the hang fire condition to the surface and the surface may in turn communicate downhole so that the upstream switches (1802, 1801) and guns (1806, 1805) react accordingly. Hang fire detection may substantially improve the safety when the gun string assembly is pulled out of the wellbore casing. According to yet another preferred exemplary embodiment, the sensing port detects pressure pulses to arm or disarm a switch. For example, a switch may detect 5 pressure pulses to arm the current switch. Similarly, a 4 pulse signal may indicate to bypass the current switch and a 3 pulse signal may indicate to fire the current switch. The pressure pulses are generated through pumping the pressure up or down from the surface of the wellbore. The plurality of outputs may be configured to communicate the output of the external port to surface and react accordingly by sending a signal to the integrated switch through one of the plural inputs. For

example, if the external port (1704) detects excess temperature in the switch (1802) or gun (1805), a signal may be sent through an output (1702) to a monitoring system at the surface or to an operator. The monitoring system may react and send a communication signal to disarm the switch through one of the plurality of input signals (1701). It should be noted that the plural inputs and outputs may be utilized as a feedback mechanism to detect faults, react to faults, and arm/disarm switches. A real time monitor may be established with the feedback mechanism built into the input and output signals. According to a preferred exemplary embodiment a select fire system for controlling operations in a gun string assembly (1800) comprises plurality of perforating guns (1804, 1805, 1806) and a plurality of switch subs (1801, 1802, 1803) mechanically coupled in the gun string assembly. Each of the plurality of switch subs may further comprise a switching element (1700), plurality of input links (1701), and plurality of output links (1702). The switching element further comprising environmental sensing ports (1704) configured to sense well conditions, perforating gun conditions, and/or input conditions from surface. The plurality of input links (1701) may be operatively and electrically connected to at least one of the plurality of perforating guns and/or at least one of the plurality of switch subs. Similarly, the plurality of output links (1702) may be operatively and electrically connected to at least one of the plurality of perforating guns and/or at least one of the plurality of switch subs. For example, with reference to FIG. 18 (1800), input links (1701) for a switching element in sub (1802) may be electrically connected to perforating guns (1805, 1804) and to subs (1801, 1803). Similarly, output links (1702) for a switching element in sub (1802) may be electrically connected to perforating guns (1805, 1806) and to subs (1801, 1803). According to a preferred exemplary embodiment each of the plurality of switch subs are configured to electronically communicate with at least one or more of the plurality of switch subs through at least one of the plurality of input links and/or plurality of output links. For example, sub (1802) may electronically communicate with sub (1801) or sub (1803). The electronic communication may be achieved with one or more wires. For example, one wire may be used for communicating 2 (2^1) states of information, two wires may be used for communicating 2 (2^2) states of information, three wires may be used for communicating 8 (2^3) states of information and so on. A communication protocol may be specifically developed between subs. For example, there might be constant pulses from one sub to another to indicate that each of the subs is functioning or alive. Alternatively, a signal might be encoded to indicate a skip, arm, disarm or reset a circuit in the switching element. A unidirectional ASCII RS232 or a bi directional ASCII RS232 may also be used for communication between switches. It should be noted that any communication protocol ordinarily used in the art may be selected to communicate between subs and perforating guns with one or more wires electrically connected. According to another preferred exemplary embodiment each of the plurality of switch subs may electronically communicate with a wellhead through at least one of the plurality of input links (1701) or through at least one of the plurality of output links (1702). For example, a through wire may be connected from the wellhead to the downstream most perforating that may in turn be connected through to the gun string assembly.

FIG. 19 (1900) generally illustrates an exemplary, switching element comprising a plurality of inputs (1904), plurality of outputs (1907), a logic block (1902), a state machine (1901), a timer (1911), a logic controller (1910), a memory (1912), and an environmental sensor port (1903). The inputs (1904) may further be connected to an input bus (1906) and the outputs (1907) may be connected to an output bus

(1908). The inputs (1904) may be routed to the logic block via the input bus (1906). The number of inputs (1904) may be range from 1 to 15, each representing a bit of information. Each of the inputs (1904) may be connected externally to outputs of another sub, a perforating gun or a combination thereof. In some instances one or more of the inputs may be input signals from the surface. For example, if the number of inputs are 8, the 8 input signals may be a combination of 4 from a downstream sub, 2 from a perforating gun and 2 from the surface. The input combinations may be designed based on the communication protocol chosen between subs and guns and the communication requirements from the surface. Similarly, the outputs (1907) may be a combination that depends on the communication protocol.

The logic block (1902) may further be designed to have inputs and one or more outputs (1909). For example, the two inputs (1919, 1929) may be outputs from two pressure switches (1918, 1928) respectively. According to a preferred exemplary embodiment a logic output of each of the plurality of pressure switches is input to a logic block. The pressure switches may be configured to detect and react to pressure in the downstream perforating gun. With respect to FIG. 18, the environmental sensor port in sub (1802) may be designed to detect and react to pressure in gun (1805). According to a preferred exemplary embodiment the switching element further comprises one or more pressure switches configured to sense pressure in a downstream gun. For example, switching element in sub (1803) senses pressure in gun (1804). Additionally, all other switching elements in other subs (1801, 1802) receive information on the pressure sensed by environmental sensor in sub (1803).

FIG. 20 (2000) generally illustrates a chart of pressure sensed by environmental sensing port in sub (1803) of a downstream perforating gun. For example, pressure sensed by environmental sensing port (1903) in sub (1803) of a downstream perforating gun (1804) may be generally illustrated by the chart of FIG. 20 (2000). The chart in FIG. 20 is a plot of pressure (2002) in a downstream gun as detected by environmental sensing port vs time (2001). Plot (2004) indicates an output (1919) of pressure switch (1918) and plot (2005) indicates an output (1929) of pressure switch (1928). The pressure switch (1918) outputs a logical 0 when the pressure in gun (1804) as detected by environmental sensing port (1903) is less than 500 psi and an output of logical 1 when the pressure is greater than 500 psi. Similarly, the pressure switch (1928) outputs a logical 0 when the pressure in gun (1804) as detected by environmental sensing port (1903) is less than 10,000 psi logical 1 when the pressure is greater than 10,000 psi. Table 1.0 shows a logical truth table of inputs (1919, 1929) and output (1909) to logical block (1902). In a preferred exemplary embodiment the logical block may be a NAND gate. According to another preferred exemplary embodiment the logical block may be a logical gate selected from a group comprising: NAND, NOR, OR, AND, XOR, INV or combination thereof.

TABLE 1.0

PS1 (<500 psi) (1919)	PS2 (>10,000 psi) (1929)	Output (1909)
0	0	0
1	0	0
0	1	0
1	1	1

As illustrated in FIG. 20, when a perforation event occurs in a perforating gun (1804), the environmental sensor port

(1903) may detect a pressure of greater than 10,000 psi. The pressure switch (1918) switches and outputs (1919) a logical 1 since the pressure is greater than 500 psi. Similarly, the pressure switch (1928) outputs (1929) a logical pulse for a pulse period (2008) since the pressure is greater than 10,000 psi for a short duration. As indicated in FIG. 20, the pulse period (2008) may be calculated from time (2006) to time (2007) for output (1929) as illustrated in plot (2005). The output (1919) from pressure switch (1918) may switch from a logical 0 to a logical 1 at time (2006) and remain at logical 1 as illustrated in plot (2004). The output (1909) signal from the logic block (1902) may be a pulse signal illustrated in plot (2003). A “gun fired” signature may be determined when the output signal (1909) pulses for a pulse period. A proper “gun fired” is determined if the period of the pulse period (2008) is within an acceptable pulse period. However, if the pulse period (2008) in the output signal (1909) is greater than the acceptable pulse period or zero, then it may indicate a failed or improper gun firing condition. For example, if the pressure in gun (1805) as read by sensor port in sub (1802) is 7000 psi, then the output signal (1909) may not pulse for the acceptable pulse period or may not pulse at all. This may indicate a failed condition. For example a flooding condition may pressure up the gun to well pressure at 7000 psi that may be detected by the switching element. In current art, the gun string assembly is pulled out if a failed condition exists. However, according to preferred exemplary embodiment, the switching element may communicate to other switching elements and bypass or disarm the failed gun. With respect to FIG. 18, if switching element in sub (1802) detects a failed condition in gun (1805), switching element in sub (1802) sends a fault signal to sub (1803) and bypasses to switching element in sub (1801). Switching element in sub (1801) enters a ready state and determines if gun (1806) is functional, then arms switching element in sub (1802) to fire gun (1806). Therefore, the communication between switches enables a switching element to be bypassed without the need for a signal from the surface as currently used in select fire switches. The gun fired signature may be communicated to switching elements in other subs (1802, 1803) which in turn react and switch states accordingly. A state machine (1901) in switching element (1900) may receive the output from logical block (1902) and one or more of the inputs (1904). The state machine may change states and output one or more signals to output bus (1908). A timer (1911) may count up or down to track the time elapsed between states or within a particular state. The timer may further output a signal or an interrupt that may be utilized to determine a fault or a failed condition. According to a preferred exemplary embodiment the switching element is configured with a timer configured to track elapsed time between events in each of the plurality of switch subs. A controller (1910) may keep track of the status of the switching element and communicate to other switching elements, perforating guns or surfaces with a pre-negotiated communication protocol. A memory element (1912) may store information pertaining to the status of the switching element and may interact with the state machine and controller. According to a preferred exemplary embodiment memory in the switching element is configured to track or store a state of the plurality of switch subs. According to another preferred exemplary embodiment a logic output from the logic controller determines a state of each of the plurality of switch subs.

FIG. 21 (2100) generally illustrates a state diagram for each of the switching elements in the subs. The number of states in the state diagram may range from 2 to 10. A first

state (2101), second state (2102) and a third state (2103) may comprise the state machine. According to a preferred exemplary embodiment, the first state, the second state, and the third state are selected from a group comprising: READY SHUNTED, READY ARMED, READY DISARMED, BYPASSED, FIRE, or FAULTED. “READY SHUNTED” may be defined as a state where the fire wire of the detonator is connected to ground. “READY DISARMED” may be defined as a state where the fire wire of the detonator is not connected to a wire capable of generating a firing signal such as a through wire. “READY ARMED” may be defined as a state where the fire wire of the detonator is connected to a wire capable of generating a firing signal such as a through wire. “BYPASSED” may be defined as state where the switch is by passed and not capable of arming. “FAULTED” may be defined as a state where the switch enters a fault condition or a failed condition. “FIRE” may be defined as a state when the perforating attached to the switch sub has fired. The state machine may transition from one state to another state through a first trigger condition, a second trigger condition or a third trigger condition. The trigger conditions are generally shown as 2104, 2105, 2106, 2107, 2108, and 2109. A timer may track time elapsed when the state machine changes state from one state to another state in the switching element. A fault condition may be detected upon expiration of the timer in the switching element. A first switching element in a first sub may bypass a second switching element in a second sub when a fault condition is detected in the second switching element. According to a preferred exemplary embodiment, the first trigger condition, the second trigger condition, and the third trigger condition are selected from a group comprising: environment conditions, perforating gun conditions, or input conditions from surface. The perforation conditions may be firing or non-firing of a downhole perforating gun. Alternatively, the perforating gun conditions may be cook up, flooding or hang fire conditions. The environment conditions are selected from a group comprising: pressure, temperature, or fluid composition. The fluid composition may be chemical composition or physical composition such as a conductive fluid. The conductive fluid may alter the electrical characteristics of the conducting wires to the detonator, sub, and/or the switching element. A circuit comprising a limiting amplifier may be attached to the inputs of a detonator to measure and monitor the electrical resistance through a detonator. The monitored detonator may provide indication of functioning of the detonator and may trip a fuse to indicate a failure condition. The failure condition due to the electrical resistance due to the presence of conductive fluid may be informed to an operator with an encoded message. The measurement of electrical resistance through the detonator may be designed with one or a combination of circuit elements such as a limiting amplifier, diodes, capacitors, resistors and/or transistors. The input conditions may be selected from a group comprising: sequencing of firing, actuating, arming or bypassing. A first action may be performed in the first state, a second action may be performed in the second state and a third action may be performed in the third state. According to a preferred exemplary embodiment, the first action, the second action, and the third action are selected from a group comprising: communicating to a downstream switch sub, communicating to an upstream switch sub, or communicating to wellhead. According to another preferred exemplary embodiment, a switch sub communicates with another switch sub through at least one conducting wire.

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FIG. 22 (2200) generally illustrates an example of states in state machines in each of the switching elements in switch subs (1801, 1802, 1803). The state machine (2201) in switching element in sub (1803) may transition from READY SHUNTED to READY ARMED to FAULT. The state machine (2202) in switching element in sub (1802) may transition from READY SHUNTED to BYPASS. The state machine (2203) in switching element in sub (1801) may transition from READY SHUNTED to READY ARMED. For example, if the pressure in gun (1805) as read by sensor port in sub (1802) is 7000 psi, then the output signal (1909) may not pulse for the acceptable pulse period or may not pulse at all. This may indicate a failed condition. For example a flooding condition may pressure up the gun to well pressure at 7000 psi that may be detected by the switching element. In current art, the gun string assembly is pulled out if a failed condition exists. However, according to preferred exemplary embodiment, the switching element may communicate to other switching elements and bypass or disarm the failed gun. With respect to FIG. 18, if switching element in sub (1802) detects a failed condition in gun (1805), switching element in sub (1802) sends a fault signal to sub (1803) and bypasses to switching element in sub (1801). Switching element in sub (1801) enters a ready state and determines if gun (1806) is functional, then arms switching element in sub (1802) to fire gun (1806). Therefore, the communication between switches enables a switching element to be bypassed without the need for a signal from the surface as currently used in select fire switches. The gun fired signature may be communicated to switching elements in other subs (1802, 1803) which in turn react and switch states accordingly.

FIG. 23 (2300) generally illustrates an example of states in state machines in each of the switching elements in switch subs (1801, 1802, 1803) indicating a proper functioning of the perforating guns. The state machine (2301) in switching element in sub (1803) may transition from READY SHUNTED to READY ARMED to FIRE. The state machine (2202) in switching element in sub (1802) may transition from READY SHUNTED to READY ARMED. The state machine (2203) in switching element in sub (1801) may remain at READY SHUNTED.

Preferred Exemplary Select Fire Operating Method Embodiment (2400)

As generally seen in the flow chart of FIG. 23 (2400), a preferred exemplary method operating in conjunction with a select fire system for controlling perforation operation of each of a plurality of switch subs in a gun string assembly may be generally described in terms of the following steps:

- (1) deploying the select fire system in first state in a wellbore casing (2401);
- (2) detecting a first trigger condition (2402);
- (3) performing a first action and transitioning to a second state or to a third state (2403);
- (4) detecting a second trigger condition (2404);
- (5) performing a second action and transitioning to a third state or to the first state (2405);
- (6) detecting a third trigger condition (2406); and
- (7) performing a third action and transitioning (2407).

Preferred Exemplary Self-detection Failure Method Embodiment (2500)

As generally seen in the flow chart of FIG. 25 (2500), a preferred exemplary self-detection failure method operating

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in conjunction with a select fire system for controlling perforation operation of each of a plurality of switch subs in a gun string assembly may be generally described in terms of the following steps:

- (1) deploying said select fire system into a wellbore casing (2501);

The gun assembly of FIG. 18 (1800) may be deployed into the wellbore casing.

- (2) detecting a failure condition in a switching element in a first sub (2502);

In current art, the gun string assembly is pulled out if a failed condition exists. In existing select fire systems, a signal is sent to an operator at the wellhead with information on the failure condition in a perforating gun. The wellhead may in turn bypass the perforating gun through a communication signal. However, according to preferred exemplary embodiment, the switching element in the first sub may communicate to other switching elements in other subs and bypass or disarm the perforating gun without the need to communicate to wellhead. The ability to communicate between switching elements in subs eliminates the need for communicating back and forth to the wellhead. A more reliable system may be accomplished and the gun string assembly is not pulled out if one of the perforating guns fails. With respect to FIG. 18, if switching element in sub (1802) detects a failed condition in gun (1805), switching element in sub (1802) sends a fault signal to sub (1803). An operator may be informed of the failure condition. The information may be communicated immediately or after a time delay. The information may include parameters such as an encoded message for the failure condition, the identity of the perforating gun and the sub. An interrupt signal may be generated from the controller in the switching element and followed with an information message.

- (3) disarming the perforating gun attached to the first sub (2503);

switching element in sub (1802) sends a fault signal to sub (1803) and bypasses to switching element in sub (1801).

- (4) bypassing control to an upstream sub (2504); and
- (5) performing a perforation event on a perforating gun attached to the upstream sub (2504).

Switching element in sub (1801) enters a ready state and determines if gun (1806) is functional, then arms switching element in sub (1802) to fire gun (1806).

System Summary

The present invention system anticipates a wide variety of variations in the basic theme of perforating, but can be generalized as a select fire system for controlling operations in a gun string assembly, the system comprising a plurality of perforating guns and a plurality of switch subs mechanically connected in the gun string assembly; each of the plurality of switch subs further comprising:

- (a) switching element;
 - (b) plurality of input links; and
 - (c) plurality of output links;
- wherein

the switching element further comprising environmental sensing ports configured to sense well conditions, perforating gun conditions, and input conditions from surface;

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the plurality of input links are configured for operative electrical connections to at least one of the plurality of perforating guns, at least one of the plurality of switch subs; and

the plurality of output links are configured for operative electrical connections to at least one of said plurality of perforating guns, at least one of said plurality of switch subs.

This general system summary may be augmented by the various elements described herein to produce a wide variety of invention embodiments consistent with this overall design description.

Method Summary

The present invention method anticipates a wide variety of variations in the basic theme of implementation, but can be generalized as a select fire operating method, the method operating in conjunction with a select fire system for controlling perforation operation of each of a plurality of switch subs in a gun string assembly;

wherein the method comprises the steps of:

- (1) deploying the select fire system in a first state in a wellbore casing;
- (2) detecting a first trigger condition;
- (3) performing a first action and transitioning to a second state or to a third state;
- (4) detecting a second trigger condition;
- (5) performing a second action and transitioning to a third state or to the first state;
- (6) detecting a third trigger condition; and
- (7) performing a third action and transitioning to the first state or to the second state.

This general method summary may be augmented by the various elements described herein to produce a wide variety of invention embodiments consistent with this overall design description.

System/Method Variations

The present invention anticipates a wide variety of variations in the basic theme of oil and gas perforations. The examples presented previously do not represent the entire scope of possible usages. They are meant to cite a few of the almost limitless possibilities.

This basic system and method may be augmented with a variety of ancillary embodiments, including but not limited to:

An embodiment wherein each of the plurality of switch subs are configured to electronically communicate with at least one or more of the plurality of switch subs through at least one of the plurality of input links.

An embodiment wherein each of the plurality of switch subs are configured to electronically communicate with at least one or more of the plurality of switch subs through at least one of the plurality of output links.

An embodiment wherein each of the plurality of switch subs are configured to electronically communicate with a wellhead through at least one of the plurality of input links or through at least one of the plurality of output links.

An embodiment wherein the switching element further comprise one or more pressure switches configured to sense pressure in a downstream gun.

An embodiment wherein the switching element is configured with a timer; the timer configured to track elapsed time between events in each of the plurality of switch subs.

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An embodiment wherein the switching element is configured with a memory; the memory configured to track store a state of the plurality of switch subs.

An embodiment wherein the environmental sensing ports are configured with a plurality of pressure switches; the plurality of pressure switches are configured to sense pressure of a downhole perforating gun.

An embodiment wherein a binary logic output of each of the plurality of pressure switches is input to a logic controller.

An embodiment wherein the logic output from the logic controller determines a state of each of the plurality of switch subs.

An embodiment wherein the first state, the second state, and the third state are selected from a group comprising: READY SHUNTED, READY ARMED, READY DISARMED, BYPASSED, or FAULTED.

An embodiment wherein the first trigger condition, the second trigger condition, and the third trigger condition are selected from a group comprising: environment conditions, perforating gun conditions, or input conditions from surface.

An embodiment wherein the first action, the second action, and the third action are selected from a group comprising: communicating to a downstream switch sub, communicating to an upstream switch sub, and communicating to a wellhead.

An embodiment wherein a switch sub communicates with another switch sub through at least one conducting wire.

An embodiment wherein the perforation conditions are firing or non-firing of a downhole perforating gun.

An embodiment wherein a timer tracks time elapsed when a state changes from one state to another state in the switch sub.

An embodiment wherein a fault condition is detected upon expiration of the timer in the switching element.

An embodiment wherein a first switch subs bypasses a second switch sub when a fault condition is detected in the second switch sub.

An embodiment wherein the environment conditions are selected from a group comprising: pressure, temperature, or fluid composition.

An embodiment wherein the perforating gun conditions are cook up, flooding or hang fire.

An embodiment wherein the input conditions are selected from a group comprising: sequencing of firing, actuating, arming or bypassing.

One skilled in the art will recognize that other embodiments are possible based on combinations of elements taught within the above invention description.

CONCLUSION

A select fire system and method for controlling operations in a gun string assembly comprising a perforating guns and switch subs mechanically connected in the gun string assembly has been disclosed. Each of the switch subs further comprises a switching element, input links and output links. The switch subs and perforating guns communicate with each other through the input and output links. The switching elements keeps track of the state of the sub and switches states based on trigger conditions such as environment conditions, perforating gun conditions, or input conditions from surface. A self-detecting method for detecting failures

in a perforating gun and acting on the failure without the need for pulling the gun string assembly out of the wellbore is also disclosed.

What is claimed is:

1. A select fire system for controlling operations in a gun string assembly, the select fire system comprising:

a plurality of perforating guns; and
a plurality of switch subs mechanically connected in the gun string assembly, each of the plurality of switch subs comprising:

(a) a switching element comprising environmental sensing ports configured to sense at least one of well conditions, perforating gun conditions, and input conditions from surface;

(b) a plurality of input links configured for operative electrical connections to at least one of the plurality of perforating guns; and

(c) a plurality of output links configured for operative electrical connections to at least another one of the plurality of perforating guns.

2. The select fire system claim 1 wherein each of the plurality of switch subs are configured to electronically communicate with at least one or more other switch subs of the plurality of switch subs through at least one of the plurality of input links.

3. The select fire system claim 1 wherein each of the plurality of switch subs are configured to electronically communicate with at least one or more other switch subs of the plurality of switch subs through at least one of the plurality of output links.

4. The select fire system claim 1 wherein each of the plurality of switch subs are configured to electronically communicate with a wellhead through at least one of said plurality of input links or through at least one of the plurality of output links.

5. The select fire system of claim 1 wherein the switching element further comprise one or more pressure switches configured to sense pressure in a downstream gun.

6. The select fire system of claim 1 wherein the switching element is configured with a timer configured to track elapsed time between events in each of the plurality of switch subs.

7. The select fire system of claim 1 wherein the switching element is configured with a memory configured to store a state of the plurality of switch subs.

8. The select fire system of claim 1 wherein the environmental sensing ports are configured with a plurality of pressure switches; the plurality of pressure switches are configured to sense pressure of a downhole perforating gun.

9. The select fire system of claim 8 wherein a binary logic output of each of the plurality of pressure switches is input to a logic controller.

10. The select fire system of claim 9 wherein the logic output from the logic controller determines a state of each of the plurality of switch subs.

11. The select fire system of claim 1, further comprising: a self-detection failure feature, operating in conjunction with the select fire system, for controlling perforation operation of each of the plurality of switch subs in the gun string assembly by detecting a failure condition in a switch sub of the plurality of switch subs, disarming an appropriate perforating gun of the gun string, and bypassing to an upstream switch sub of the plurality of switch subs.

12. The select fire system of claim 11 wherein the self-detection failure feature includes an operator alert configured to alert an operator when the failure condition is detected.

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